NPS ARCHIVE
1969
TUFTS, H.

EMERGENCY ASCENT TRAJECTORIES FOR DEEP SUBMERSIBLES

by

HERBERT WILLIAM TUFTS, III

June, 1969

DUDLEY KNOX LIBRARY
NAVAL POSTGRADUATE SCHOOL
MONTEREY, CA 93943-5101

EMERGENCY ASCENT TRAJECTORIES FOR DEEP SUBMERSIBLES

by

HERBERT WILLIAM TUFTS, III

B.S., Virginia Polytechnic Institute

(1963)

SUBMITTED IN PARTIAL FULFILLMENT

OF THE REQUIREMENTS FOR THE DEGREE OF

NAVAL ENGINEER

AND THE DEGREE OF

MASTER OF SCIENCE IN OCEAN ENGINEERING

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June, 1969

NPS ARCHIVE
1964
TUFTS, H.

~~Thesis
T8~~

LIBRARY
NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIF. 93940

ABSTRACT

EMERGENCY ASCENT TRAJECTORIES FOR DEEP SUBMERSIBLES

by

HERBERT WILLIAM TUFTS, III

Submitted to the Department of Naval Architecture and Marine Engineering on May 21, 1969 in partial fulfillment of the requirements for the degree of Naval Engineer and the degree of Master of Science in Ocean Engineering.

After a brief discussion of the need for predicting the emergency ascent trajectory of a submersible and the means by which a mathematical model of an ascent can be derived, the second order, coupled equations of motion for a vehicle with varying mass and center of mass are derived.

The equations of motion are then solved by a numerical step-wise procedure which is ameanable to programming on a digital computer.

Ascent trajectories are calculated using data from model experiments on the Deep Submergence Rescue Vehicle.

The tests indicate that two dimensional, vertical plane, equations are all that are necessary to determine an ascent through an undisturbed medium, but are insufficient once the vehicle is disturbed from its vertical plane.

Thesis Supervisor: Martin A. Abkowitz

Title: Professor of Naval Architecture

ACKNOWLEDGEMENTS

I wish to acknowledge the advice and assistance of the supervisor of this thesis, Professor Martin A. Abkowitz. I would particularly like to express my thanks for the opportunity to work under his direction.

The assistance and encouragement of Commander Sherman Reed in my dealings with NSRDC are greatfully acknowledged.

All computer programs were written for and executed by the IBM 360 Digital Computer of the Information Processing Center of Massachusetts Institute of Technology.

TABLE OF CONTENTS

TITLE PAGE i

ABSTRACT ii

ACKNOWLEDGEMENTS iii

TABLE OF CONTENTS iv

NOMENCLATURE vi

INTRODUCTION 1

CHAPTER I: FORMULATION OF THE PROBLEM 5

I - 1 Assumptions 5

I - 2 Initial and Other Conditions 6

CHAPTER II: EQUATIONS OF MOTION 7

II - 1 General 7

II - 2 Axis Systems 7

II - 3 Conservation of Momentum Equations 11

II - 4 Gravity Forces 20

II - 5 Hydrodynamic Forces 21

II - 6 Equations of Motion for Free Ascent 41

II - 7 Summary 45

CHAPTER III: SOLUTION OF THE EQUATIONS OF MOTION 46

III - 1 Revised Equations of Motion 47

III - 2 Stepwise Linear Solution 52

III - 3 One Dimensional Ascent Trajectory 54

III - 4 Summary 57

CHAPTER IV: RESULTS AND CONCLUSIONS 58

IV - 1 Results of Computer Simulations 58

IV - 2 Conclusions and Recommendations 62

REFERENCES 63

APPENDIX A: COMPUTER PROGRAM FOR ASCENT TRAJECTORIES 65

A - 1 General 65

A - 2 Input - Output 68

A - 3 Description of Namelists 72

A - 4 Program Listings 78

APPENDIX B: TEST VEHICLE GEOMETRIC AND CONTROL CHARACTERISTICS 94

APPENDIX C: INPUT AND OUTPUT FOR TEST VEHICLE 101

APPENDIX D: A PROGRAM TO COMPUTE ONE DIMENSIONAL ASCENT TRAJECTORIES 105

NOMENCLATURE

Symbol	Dimensionless Form	Definition
A_B, A_E		Body and earth fixed axis systems respectively
B	$B' = B/\frac{1}{2}\rho l^2 U^2$	Buoyancy force, positive upward
CB		Center of buoyancy of submersible
CG		Center of gravity or mass of submersible
I_G, I_o		Inertial tensor (3 x 3) about vehicle CG and vehicle origin respectively
I_{xx}	$I'_{xx} = I_{xx}/\frac{1}{2}\rho l^5$	Moment of inertia of submersible about x axis
I_{yy}	$I'_{yy} = I_{yy}/\frac{1}{2}\rho l^5$	Moment of inertia of submersible about y axis
I_{zz}	$I'_{zz} = I_{zz}/\frac{1}{2}\rho l^5$	Moment of inertia of submersible about z axis
I_{xy}	$I'_{xy} = I_{xy}/\frac{1}{2}\rho l^5$	Product of inertia of submersible about xy plane

I_{xz}	$I'_{xz} = I_{xz}/\frac{1}{2}\rho l^5$	Product of inertia of submersible about xz plane
I_{yz}	$I'_{yz} = I_{yz}/\frac{1}{2}\rho l^5$	Product of inertia of submersible about yz plane
K, M, N	$K' = K/\frac{1}{2}\rho l^3 U^2$	Rolling, pitching and yawing moments respectively
K_u	$K'_u = K_u/\frac{1}{2}\rho l^3 U = \partial K'/\partial u'$	Typical static moment derivative; derivative of a moment component with respect to a velocity component, $\partial K/\partial u$
$K_{\dot{u}}$	$K'_{\dot{u}} = K_{\dot{u}}/\frac{1}{2}\rho l^4 = \partial K'/\partial \dot{u}'$	Typical moment of inertia coefficient; derivative of a moment component with respect to an acceleration component, $\partial K/\partial \dot{u}$
K_p	$K'_p = K_p/\frac{1}{2}\rho l^4 U = \partial K'/\partial p'$	Typical rotary moment derivative with respect to an angular velocity component, $\partial K/\partial p$

$K_{\dot{p}}$	$K'_{\dot{p}} = K_{\dot{p}}/\frac{1}{2}\rho l^5 = \partial K'/\partial \dot{p}'$	Typical moment of inertia coefficient; derivative of a moment component with respect to an angular acceleration component, $\partial K/\partial \dot{p}$
K_{vw}	$K'_{vw} = K_{vw}/\frac{1}{2}\rho l^3 = \partial^2 K'/\partial v'\partial w'$	Typical second order moment coefficient; derivative of a moment component with respect to the square of a velocity component or the product of two velocity components, $\partial^2 K/\partial v \partial w$
K_{vq}	$K'_{vq} = K_{vq}/\frac{1}{2}\rho l^4 = \partial^2 K'/\partial v'\partial q'$	Typical second order moment coefficient; derivative of a moment component with respect to the product of a velocity component with an angular velocity component, $\partial^2 K/\partial v \partial q$
K_{pq}	$K'_{pq} = K_{pq}/\frac{1}{2}\rho l^5 = \partial^2 K'/\partial p \partial q$	Typical second order moment coefficient; derivative of a moment component with respect to the square of an angular velocity component or the product of two angular velocity components, $\partial^2 K/\partial p \partial q$

K_*	$K'_* = K_*/\frac{1}{2}\rho l^3 u^2$	Typical moment coefficient when body angles (α, β) and control surface angles are zero
l	$l' = l/l = 1$	Characteristic length of the submersible
m	$m' = m/\frac{1}{2}\rho l^3$	Mass of submersible, including water in ballast tanks
O		Origin of body axes
p, q, r	$p' = pl/U$	Angular velocities of roll, pitch and yaw, respectively
$\dot{p}, \dot{q}, \dot{r}$	$\dot{p}' = \dot{p} l^2/U^2$	Angular accelerations of roll, pitch, and yaw, respectively
t	$t' = t\, U/l$	Time
T_A, T_B		Angular and translational velocity transformation matrices, respectively; transformation is from body to earth axes
T_f, T_v		Kinetic energy of fluid and vehicle, respectively

u, v, w	$u' = u/U$	Longitudinal, transverse and normal components, respectively of the velocity of the origin of body axes relative to the fluid
$\dot{u}, \dot{v}, \dot{w}$	$\dot{u}' = \dot{u}l/U^2$	Longitudinal, transverse and normal components, respectively of the acceleration of the origin of body axes relative to the fluid
U	$U' = U/U = 1$	Velocity of origin of body axes relative to the fluid
∇	$\nabla' = \nabla/l^3$	Volume of submersible
W	$W' = W/\frac{\rho}{2} l^2 U^2$	Weight of submersible
x, y, z	$x' = x/l$	Body axes, or coordinates of a point relative to body axes
x_B, y_B, z_B	$x'_B = x_B/l$	Coordinates of the center of buoyancy relative to body axes
x_G, y_G, z_G	$x'_G = x_G/l$	Coordinates of the center of gravity relative to body axes

x_o, y_o, z_o	$x'_o = x_o/l$	Fixed or inertial axes, or coordinates of a point relative to fixed axes
$\dot{x}_E, \dot{y}_E, \dot{z}_E$	$\dot{x}'_E = \dot{x}_E/U$	Longitudinal, transverse and normal components, respectively of the velocity of the origin of body axes relative to the inertial axes
X, Y, Z	$X' = X/\frac{1}{2}\rho l^2 U^2$	Longitudinal, lateral and normal components, respectively, of hydrodynamic force on the submersible
X_u	$X'_u = X_u/\frac{1}{2}\rho l^2 U = \partial X'/\partial u'$	Typical static force derivative of a force component with respect to a velocity component, $\partial X/\partial u$
$X_{\dot{u}}$	$X'_{\dot{u}} = X_{\dot{u}}/\frac{1}{2}\rho l^3 = \partial X'/\partial \dot{u}'$	Typical inertia coefficient; derivative of a force component with respect to an acceleration component, $\partial X/\partial \dot{u}$
X_p	$X'_p = X_p/\frac{1}{2}\rho l^3 U = \partial X'/\partial p'$	Typical rotary force derivative; derivative of a force component with respect to an angular velocity component, $\partial X/\partial p$

$X_{\dot p}$	$X_{\dot p} = X_{\dot p}/\frac{1}{2}\rho l^4 = \partial X'/\partial \dot p'$	Typical inertia coefficient; derivative of a force component with respect to an angular acceleration component, $\partial X/\partial \dot p$
X_{uw}	$X'_{uw} = X_{uw}/\frac{1}{2}\rho l^2 = \partial^2 X'/\partial u \partial w$	Typical second order force coefficient; derivative of a force component with respect to the square of a velocity component or the product of two velocity components, $\partial^2 X/\partial u \partial w$
X_{vr}	$X'_{vr}/\frac{1}{2}\rho l^3 = \partial^2 X'/\partial v \partial r$	Typical second order force coefficient; derivative of a force component with respect to the product of a velocity component, $\partial^2 X/\partial v \partial r$
X_{rp}	$X'_{rp} = X_{rp}/\frac{1}{2}\rho l^4 = \partial^2 X'/\partial r \partial p$	Typical second order force coefficient; derivative of a force component with respect to the square of an angular velocity component or the product of two angular velocity components, $\partial^2 X/\partial r \partial p$

X_{EFF}	$X'_{EFF} = X_{EFF}/\frac{1}{2}\rho l^2 U^2$	Typical effector force coefficient
Y_*, Z_*	$Y'_* = Y'_*/\frac{1}{2}\rho l^2 U^2$	Lateral and normal forces when body angles (α, β) and control surface angles are zero
α, β		Angles of attack and drift, respectively
γ		Specific weight of the fluid
θ, ψ, ϕ		Angles of pitch, yaw and roll respectively
ρ		Mass density of the fluid
$\rightarrow$	Vector	
$\cdot$	Time derivative $\partial/\partial t$	
$'$	Non-dimensionalized parameter	
$[M]$	Matrix	
∂	Partial derivative	
d	Derivative	

INTRODUCTION

An important operating mode of deep submersibles is the ascending and descending mode. Unlike large high speed military submarines which ascend and descend dynamically by use of a combination of speed and appendage deflection, deep submersibles depend partially and sometimes entirely, as in the case of the TRIESTE, upon buoyant ascent and descent. Of the ascending and descending operations, the most critical is during an emergency ascent in which most or all of the jettisonable weights are removed from the vehicle in order to obtain as rapid an ascent as possible.

The majority of deep submersibles fall into a class of vehicles characterized by low speed and minimal appendage streamlining. They are designed for underwater research and rescue missions which do not, except for the travel mode of the Deep Submergence Rescue Vehicle, require large speeds. They are equipped with many and diverse appendages for accomplishing their missions such as manipulator arms, lights, propulsion motors, sampling equipment, TV cameras and mating skirts, all of which effect, to varying degrees, the streamlining and hydrodynamics of these vehicles.

In order to study the motions and ascent trajectories of submersibles in normal or emergency ascent without model or full scale tests, it is necessary to develop a mathematical model of the vehicle which can accomodate the effects of varying mass and center of mass.

This work is an attempt to develop the mathematical model using a set of second order equations of motion, and solve these equations by use of a high speed digital computer.

The primary sources of material for this work are the works of Abkowitz, Dogan, Gertler and Hagen, Lamb and Strumpf, but the secondary

sources, acknowledged or not, are no less important ot the development of this work.

The problem of determining the motions of a totally submerged body has been treated by many authors, however, there appear to be only two basic means for arriving at these equations. These are by energy methods and by vector calculus.

The first method is that used by Sir Horace Lamb in his book "Hydrodynamics" which first appeared in 1879 (see ref 1). The energy method is based upon the existance of a single valued velocity-potential which implies that the motion of the fluid is entirely due to that of the submersible, and is therefore irrotational and acyclic. This method leads to a completely general set of equations representing the rigid body dynamics, but the hydrodynamic forces that result represent only the so called added mass or added inertia effects and not all the forces acting on the body. Of the forces that are missing the most important are those due to circulation, separation and vortex shedding.

The second method of developing the equations of motion is to combine a vector expansion of Newton's laws of motion, expressed as follows:

$$\vec{F} = \frac{d}{dt}\text{ (Momentum) = the vector force acting on the body} \qquad (1)$$

$$\vec{M} = \frac{d}{dt}\text{ (Angular momentum) = the vector moment acting on the body} \qquad (2)$$

with a Taylor series expansion of the hydrodynamic forces and moments expressed as:

$$\begin{matrix}\text{Forces}\\ \text{Moments}\end{matrix} = f\text{ (Properties of body; Properties of motion, Properties of fluid)} \qquad (3)$$

which reduces to

$$\frac{\vec{F}}{\vec{M}} = f \text{ (Properties of motion)} \qquad (4)$$

for a particular vehicle in a particular fluid. This method has been used by A. Strumpf in 1960 in developing his "Equations of Motion of a Submerged Body with Varying Mass" (see ref 2) and by Prof. M. A. Abkowitz in 1949 in his lecture course and notes on "The Dynamical Stability of Submarines" (see ref's 3 and 10). It too results in a completely general set of equations describing the rigid body dynamics, but its greatest asset lies in the generality of the hydrodynamic forces and moments. The hydrodynamic forces and moments obtained from a Taylor series expansion include not only all the added mass effects but also the circulation, separation and vortex shedding effects. The only limitation on this method is the availability of theoretical or experimental data to use in the equations.

From the preceeding discussion and equations (1 through 4), it is obvious that the derivation of the rigid body motion may be completely separated from the problem of developing a suitable form for the hydrodynamic effects. Therefore, the two methods of development may be broken down and part of each used.

This work shall attempt to take advantage of the simplicity of the energy development of the rigid body dynamics, while retaining the generality provided by the Taylor series expansion of the hydrodynamic forces and moments.

The solution of the equations of motion that will be developed employs a technique suggested in 1964 by G. Parissis in his solution of linearized equations of motion for heave and pitch of a ship (see ref 4)

and again in 1967 by L. M. McCloskey for the digital simulation of the DSRV control system and autopilot (see ref 5).

The coefficients used to test the solution of the equations of motion come from a series of model experiments conducted on the DSRV. The results of the computer solution will not, however, be the ascent trajectory for the DSRV since there is an assumption, in this work, of zero propulsion forces in the development of the equations of motion.

The assumptions and the statement of the problem are given in Chapter I, the equations of motion are derived in Chapter II and a method for solving the equations of motion is developed in Chapter III.

CHAPTER I

FORMULATION OF THE PROBLEM

The problem involves a deep submersible vehicle of given geometry and dimensions which is in free ascent through a stationary fluid.

I - 1 Assumptions

The vehicle is assumed to be a rigid body with no elastic deformations of a vibratory nature. It has six degrees of freedom, three translational and three rotational. We shall be interested in motions in both the horizontal and vertical planes of motion. Velocities are small. Hydrodynamic effects of second order in acceleration shall be considered negligible. The only body symmetry is port and starboard.

I - 1.1

The neglecting of vibratory motions is reasonable since the frequencies of vibration of the hull acting as an elastic body are of different orders of magnitude than the frequencies of motion and do not excite the latter. Elastic deformations due to vehicle compressability must be included since they directly affect the buoyancy of the vehicle.

I - 1.2

The interest in both planes of motion is due to the desire for as general a set of equations as possible.

I - 1.3

The assumption of small velocities is realistic in that free ascent velocities and open ocean currents are in general of order less than ten knots.

I - 1.4

The use of a set of second order equations of motion is deemed necessary to appropriately describe the hydrodynamic cross-coupling that takes place in a problem such as this. The second order acceleration effects are assumed to be zero on the basis of potential theory (see ref 1). This, however, has not been experimentally verified.

I - 1.5

Neglecting assymmetries due to relatively small appendages which are not control surfaces, there are few vehicles which operate in the ocean environment which do not possess port and starboard symmetry. For this reason the assumption of port and starboard symmetry has been made.

I - 2 Initial and Other Conditions

The vehicle is to be initially at rest relative to the inertial, earth fixed, axes. The control effectors, propellers, thrusters, rudders, dive planes, etc., are inoperable and/or in neutral position. The driving force for the vehicle shall be a decrease in weight due to jettisoning of ballast or an increase in volume due to vehicle decompression as it rises.

These conditions, though arbitrary, serve to restrict the problem to one of manageable size.

CHAPTER II

EQUATIONS OF MOTION

II - 1 General:

The derivation of the equations of motion for a rigid body in six degrees of freedom with a varying mass and center of mass follows closely that of Dr. Pierre Dogan in reference (5), which is based primarily upon the development of the equations of motion by Lamb in reference (1). The derivation of the hydrodynamic force equations follows that of Professor Martin Abkowitz in reference (3) except that, in this work, the second order terms are retained. The forces due to gravity are determined using the transformations set forth in reference (6) and the angular velocity transformations given by Professor Abkowitz in reference (7).

The axis systems necessary to describe the motions of a body and its trajectory through a fluid include a body fixed system and an inertial system.

II - 2 Axis Systems

The equations of motion for an ascending vehicle must be written in an earth fixed axis system in order to determine the trajectory of the vehicle relative to some fixed point. An additional body fixed system is required in order to describe the hydrodynamic interactions between the vehicle and the water.

II - 2.1 Inertial Axis System

The right-handed earth fixed axis system, A_E (see figure II.1), is assumed to be an inertial system for the reason that the accelerations

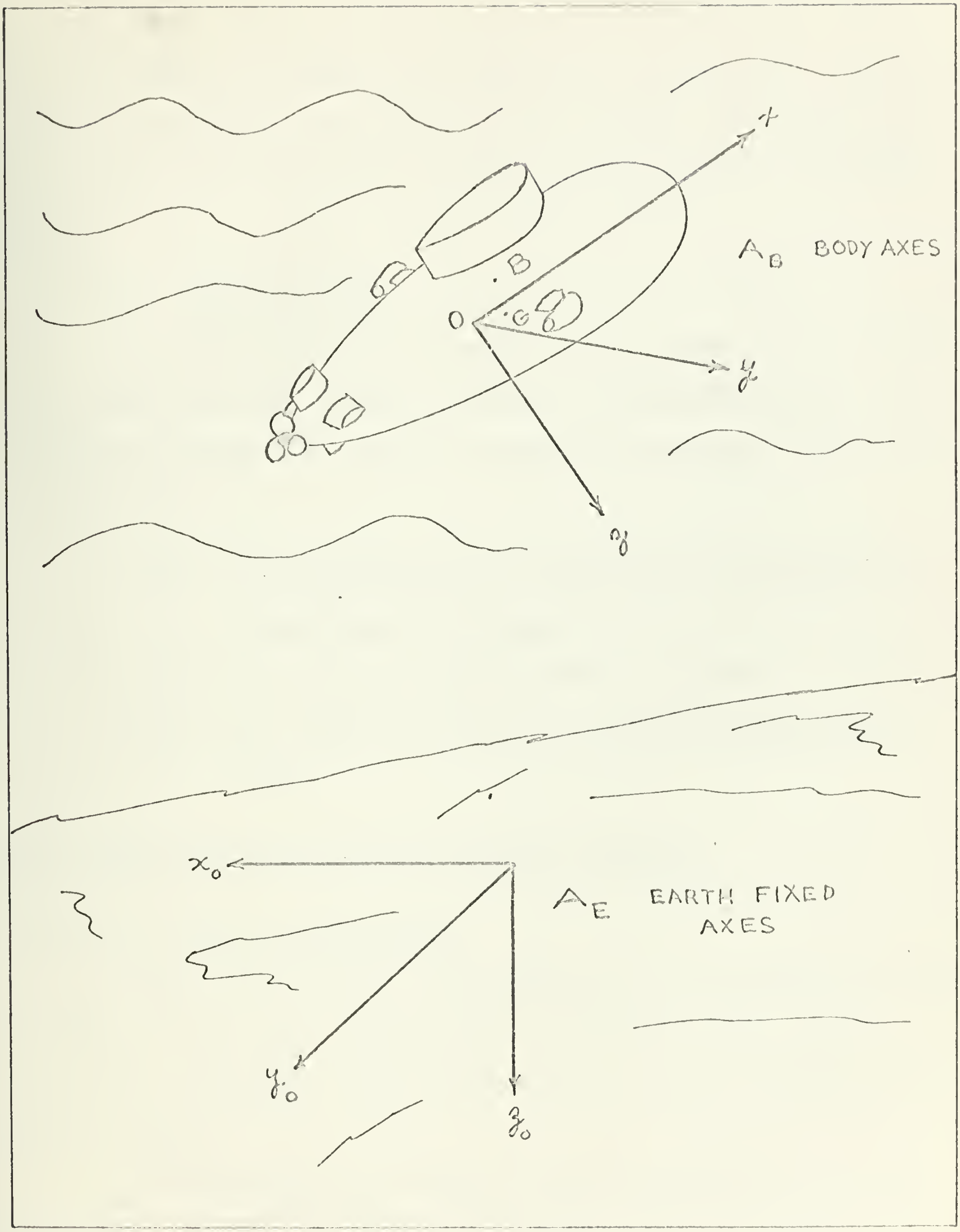


Figure 1 Coordinate Systems

of a point on the surface of the earth are an order of magnitude smaller than those which are of importance to the motions of the vehicle. A_E is an orthogonal set of axes fixed relative to the earth such that components x_E and y_E are in a horizontal plane, and the z_E axis is vertical and directed downwards.

II - 2.2 Body Axis System

The right-handed body axis system, A_B (see figure II.1), is fixed in the vehicle such that advantage is taken of the assumed principal plane of symmetry by placing the origin of the system in this plane. The axes of this system are:

x axis - the longitudinal axis, directed from the after to the forward end of the vehicle,

y axis - the transverse axis, directed to starboard,

z axis - the normal axis, directed from top to bottom (deck to keel).

The xz plane is the assumed principal plane of symmetry.

II - 2.3 Body Axes Orientation

Angular displacements of A_B relative to A_E are specified by a set of modified 'Euler angles' which are taken as positive in the sense of rotation of a right-handed screw advancing in the positive direction of the axis of rotation.

The orientation of A_B relative to A_E is described in terms of a roll angle ϕ, a pitch angle θ and a yaw angle ψ. Before defining these angles, an order of rotations must be chosen since finite rotations are not true vector quantities and do not obey the rules for adding vectors. The

order chosen here conforms to that set forth in reference (6) which is:

(1) rotate about the initial $z = z_E$ axis through an angle of yaw ψ,

(2) rotate about the new position of the $y = y_1$ axis through an angle of pitch θ,

(3) finally rotate about the new position of the $x = x$ axis through an angle of roll ϕ.

In accordance with the order of rotations above we have the following definitions:

θ - the angle of pitch; the angle of elevation of the x axis; the angle between the x axis and the horizontal plane $x_E y_E$,

ψ - the angle of yaw; the angle from the vertical plane $x_E z_E$ to the vertical plane xz_E,

ϕ - the angle of roll; the angle from the vertical xz_E plane to the principal plane of symmetry xz.

The successive rotations required to specify the orientation of the body axes relative to the earth fixed axes can be described by three orthogonal matrices $[\psi]_{z_E}$, $[\theta]_{y_1}$, $[\phi]_x$:

$$[\psi]_{z_E} = \begin{bmatrix} \cos\psi & \sin\psi & 0 \\ -\sin\psi & \cos\psi & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$[\theta]_{y_1} = \begin{bmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{bmatrix}$$

$$[\phi]_x = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\phi & \sin\phi \\ 0 & -\sin\phi & \cos\phi \end{bmatrix}$$

Unit vectors in A_B and A_E are related by an orthogonal matrix:

$$\begin{bmatrix} i_B \\ j_B \\ k_B \end{bmatrix} = T_B \begin{bmatrix} i_E \\ j_E \\ k_E \end{bmatrix}$$

where T_B is the product of the three orthogonal matrices defining the rotations:

$$T_B = [\phi]_x [\theta]_{y_1} [\psi]_{z_E}$$

$$= \begin{bmatrix} \cos\theta\cos\psi & \cos\theta\sin\psi & -\sin\theta \\ -\cos\phi\sin\psi + \sin\phi\sin\theta\cos\psi & \cos\phi\cos\psi + \sin\phi\sin\theta\sin\psi & \sin\phi\cos\theta \\ \sin\phi\sin\psi + \sin\theta\cos\phi\cos\psi & -\sin\phi\cos\psi + \cos\phi\sin\theta\sin\psi & \cos\phi\cos\theta \end{bmatrix}$$

Velocities in A_B and A_E are also related by the transformation matrix T_B:

$$\begin{bmatrix} u \\ v \\ w \end{bmatrix} = T_B \begin{bmatrix} \dot{x}_E \\ \dot{y}_E \\ \dot{z}_E \end{bmatrix}$$

The vehicle angular velocities in A_B and A_E are, however, related by a non-orthogonal matrix, which is the sum of three components along the z_E, y_1 and x axes of magnitude $\dot{\psi}$, $\dot{\theta}$ and $\dot{\phi}$.

$$\begin{bmatrix} p \\ q \\ r \end{bmatrix} = \left[\phi\right]_x \left[\theta\right]_{y_1} \begin{bmatrix} 0 \\ 0 \\ \dot{\psi} \end{bmatrix} + \left|\phi\right|_x \begin{bmatrix} 0 \\ \dot{\theta} \\ 0 \end{bmatrix} + \begin{bmatrix} \dot{\phi} \\ 0 \\ 0 \end{bmatrix}$$

$$= \begin{bmatrix} 1 & 0 & -\sin\theta \\ 0 & \cos\phi & \cos\theta\sin\phi \\ 0 & -\sin\phi & \cos\theta\cos\phi \end{bmatrix} \cdot \begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix}$$

$$= T_A \begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix}$$

II - 3 Conservation of Momentum Equations

The derivation of the dynamical equations for a vehicle with a varying mass and center of mass have been treated in two different manners by:

(1) Albert Strumpf of Davidson Lab, (see ref 2) using vector calculus, and including variations in mass, moments of inertia and CG position.

(2) Pierre Dogan of MIT Instrumentation Lab, (see ref 5), using a Langrangian formalism, including time variation of the inertial tensor, and making assumptions as to the form of the movable weights.

The treatment by Strumpf assumes a body that is a rocket, so that mass is discharged from the body. The treatment by Dogan, for the Deep Submergence Rescue Vehicle (DSRV), assumes that the mass of the body is constant but allows the position of the center of gravity to change.

The development by Dogan avoids the long vectorial derivations

involved in Strumpf's development, while sacrificing generality by not including a change in mass. This feature could be included if it were desired and so the approach by Dogan will be used.

Nine generalized velocities and coordinates are sufficient to describe the motions of the vehicle. These are: six velocities (u, v, w, p, q, r) to describe the vehicle and three coordinates (x_G, y_G, z_G) to describe the motion of the center of gravity. The following six Lagrange equations will give the needed vehicle momentum equations. (See Lamb, "Hydrodynamics" 6th Ed, page 168)

$$\frac{d}{dt}\frac{\partial T_v}{\partial u} - r\frac{\partial T_v}{\partial v} + q\frac{\partial T_v}{\partial w} = X \qquad (2.3 - 1)$$

$$\frac{d}{dt}\frac{\partial T_v}{\partial v} - p\frac{\partial T_v}{\partial w} + r\frac{\partial T_v}{\partial u} = Y \qquad (2.3 - 2)$$

$$\frac{d}{dt}\frac{\partial T_v}{\partial w} - q\frac{\partial T_v}{\partial u} + p\frac{\partial T_v}{\partial v} = Z \qquad (2.3 - 3)$$

$$\frac{d}{dt}\frac{\partial T_v}{\partial p} - w\frac{\partial T_v}{\partial v} + v\frac{\partial T_v}{\partial w} - r\frac{\partial T_v}{\partial q} + q\frac{\partial T_v}{\partial r} = K \qquad (2.3 - 4)$$

$$\frac{d}{dt}\frac{\partial T_v}{\partial q} - u\frac{\partial T_v}{\partial w} + w\frac{\partial T_v}{\partial u} - p\frac{\partial T_v}{\partial r} + r\frac{\partial T_v}{\partial p} = M \qquad (2.3 - 5)$$

$$\frac{d}{dt}\frac{\partial T_v}{\partial r} - v\frac{\partial T_v}{\partial u} + u\frac{\partial T_v}{\partial v} - q\frac{\partial T_v}{\partial p} + p\frac{\partial T_v}{\partial q} = N \qquad (2.3 - 6)$$

T_v is the vehicle total kinetic energy. X, Y, Z, K, M, N are the generalized forces and moments of which some can be further described by a potential function and others represent friction and drag.

The three Lagrange equations necessary to describe the momentum balance equation for the jettisonable ballast subsystem are assumed to reduce to quasi-steady equations defining the CG location from the integrals of the various ballast release rates.

This procedure is as much a necessity as it is a simplification

since, in the case of dropping ballast, the ballast may take almost any form from liquid mercury and iron shot to large blocks of metal or pieces of equipment. The dropping of a liquid or a granular solid can be reasonably modeled as a function of time but the dropping of chunks of metal or pieces of equipment would create singularities in a functional relationship. The obvious answer would be to use a combination of a smooth function and steps to obrain a reasonably accurate model of the deballasting of a vehicle.

There is one additional factor which also affects the decision to reduce the function to a quasi-steady process. The total ballast dropped is no more than three percent of the total vehicle weight and the rate at which it is removed is of order .3 percent of the total vehicle weight per second. This would then say that any Taylor series expansion of this function, which retained terms commesurate with the second order expansion to be used in obtaining the hydrodynamic forces, would contain at most the linear terms.

The effect of such an approximation is entirely dependent upon the length of the time interval over which the process is assumed to be steady and shall be discussed in conjunction with the computer program. Suffice it to say here, that until accurate model tests can be conducted, the effect of this assumption is truly unknown, but appears to be of inconsequential magnitude.

The equations describing the variable position of the CG in the body axis system are:

$$x_G = \frac{x_{GB} W - \sum_i^N x_i \int_{t_o}^{t} W_i \, dt}{W - \sum_i^N W_i} \qquad (2.3 - 7)$$

$$y_G = \frac{y_{GB} W - \sum_i^N y_i \int_{t_o}^{t} W_i \, dt}{W - \sum_i^N W_i} \qquad (2.3 - 8)$$

$$z_G = \frac{z_{GB} W - \sum_i^N z_i \int_{t_o}^{t} W_i \, dt}{W - \sum_i^N W_i} \qquad (2.3 - 9)$$

where x_{GB}, y_{GB}, z_{GB} are the components of the CG of the vehicle with all of the ballast, W is the vehicle weight including all jettisonable ballast, x_i, y_i, z_i are the CG's of the N jettisonable ballast weights W_i.

The vehicle kinetic energy is the sum:

$$T_v = \frac{m}{2} \vec{V}_G^2 + \tfrac{1}{2} \vec{\omega} I_G W \qquad (2.3 - 10)$$

where m, $\vec{V}_G$, I_G and $\vec{\omega}$ are the vehicle mass, the CG velocity, the inertial tensor about the CG and the angular velocity vector. Defining axes x', y', z' through the CG parallel to the vehicle body axes, one has

$$I_G = \begin{bmatrix} I_{x'x'} & I_{x'y'} & I_{x'z'} \\ I_{y'x'} & I_{y'y'} & I_{y'z'} \\ I_{z'x'} & I_{z'y'} & I_{z'z'} \end{bmatrix} \qquad (2.3 - 11)$$

where $I_{x'x'}$, $I_{y'y'}$ ..... have the usual meanings:

$$I_{x'x'} = \iiint_{V} (y'^2 + z'^2)\, dm$$

$$I_{x'y'} = \iiint_{V} (x'y')\, dm$$

Computing the components of $\vec{V}_G$ in body axes one has:

$$\vec{V}_G = (u + qz_G - ry_G + \dot{x}_G,\ v + rx_G - pz_G + \dot{y}_G,\ w + py_G - qx_G + \dot{z}_G) \qquad (2.3 - 12)$$

Substituting (2.3 - 11) and (2.3 - 12) into (2.3 - 10) one gets the kinetic energy T_v and its partial derivatives:

$$\frac{\partial T_v}{\partial u} = m\,(u + qz_G - ry_G + \dot{x}_G) \qquad (2.3 - 13)$$

$$\frac{\partial T_v}{\partial v} = m\,(v + rx_G - pz_G + \dot{y}_G) \qquad (2.3 - 14)$$

$$\frac{\partial T_v}{\partial w} = m\,(w + py_G - qz_G + \dot{z}_G) \qquad (2.3 - 15)$$

$$\begin{aligned}\frac{\partial T_v}{\partial p} &= I_{x'x'}p + I_{x'y'}q + I_{x'z'}r \\ &\quad - mz_G\,(v + rx_G - pz_G + \dot{y}_G) \\ &\quad + my_G\,(w + py_G - qx_G + \dot{z}_G)\end{aligned} \qquad (2.3 - 16)$$

$$\begin{aligned}\frac{\partial T_v}{\partial q} &= I_{y'y'}q + I_{y'z'}r + I_{y'x'}p \\ &\quad - mx_G\,(w + py_G - qx_G + \dot{z}_G) \\ &\quad + mz_G\,(u + qz_G - ry_G + \dot{x}_G)\end{aligned} \qquad (2.3 - 17)$$

$$\begin{aligned}\frac{\partial T_v}{\partial r} &= I_{z'z'}r + I_{z'x'}p + I_{z'y'}q \\ &\quad - my_G\,(u + qz_G - ry_G + \dot{x}_G) \\ &\quad + mx_G\,(v + rx_G - pz_G + \dot{y}_G)\end{aligned} \qquad (2.3 - 18)$$

The inertial tensor I_G about the CG can be algebraically related to the inertial tensor I_o about the origin (defined in x, y, z) and the distance x_G, y_G, z_G. For example:

$$I_{xx} = I_{x'x'} + m\,(z_G^2 + y_G^2)$$

$$I_{xy} = I_{x'y'} - m x_G y_G$$

Substituting these for the inertial tensor, I_G, equations (2.3 - 16) through (2.3 - 18) become:

$$\begin{aligned}\frac{\partial T_v}{\partial p} = {} & I_{xx} p + I_{xy} q + I_{xz} r \\ & - m z_G\,(v + \dot{y}_G) \\ & + m y_G\,(w + \dot{z}_G) \qquad (2.3 - 19)\end{aligned}$$

$$\begin{aligned}\frac{\partial T_v}{\partial q} = {} & I_{yy} q + I_{yz} r + I_{yx} p \\ & - m x_G\,(w + \dot{z}_G) \\ & + m z_G\,(u + \dot{x}_G) \qquad (2.3 - 20)\end{aligned}$$

$$\begin{aligned}\frac{\partial T_v}{\partial r} = {} & I_{zz} r + I_{zx} p + I_{zy} q \\ & - m y_G\,(u + \dot{x}_G) \\ & + m x_G\,(v + \dot{y}_G) \qquad (2.3 - 21)\end{aligned}$$

Substituting these equations and equations (2.3 - 13) through (2.3 - 15) (without primed subscripts) into the Lagrangian equations of motion (2.3 - 1) through (2.3 - 6), one gets the dynamical equations:

$$X = m\Big[\dot{u} - rv + qw - x_G\,(q^2 + r^2) + y_G\,(pq - \dot{r}) + z_G\,(pr + \dot{q})$$

$$+ 2q\dot{z}_G - 2r\dot{y}_G + \ddot{x}_G\Big] \qquad (2.3 - 22)$$

$$Y = m\Big[\dot{v} - pw + ru - y_G\,(r^2 + p^2) + z_G\,(qr - \dot{p}) + x_G\,(qp + \dot{r})$$

$$+ 2r\dot{x}_G - 2p\dot{z}_G + \ddot{y}_G\Big] \qquad (2.3 - 23)$$

$$Z = m\Big[\dot{w} - qu + pv - z_G\,(p^2 + q^2) + x_G\,(rp - \dot{q}) + y_G\,(rq + \dot{p})$$

$$+ 2p\dot{y}_G - 2q\dot{x}_G + \ddot{z}_G\Big] \qquad (2.3 - 24)$$

$$K = I_{xx}\dot{p} + I_{xy}\,(\dot{q} - pr) + I_{xz}\,(\dot{r} + pq) + I_{yz}\,(q^2 - r^2) + (I_{zz} - I_{yy})\,qr$$

$$- mz_G\,(\dot{v} - pw + ru + r\dot{x}_G + \ddot{y}_G)$$

$$+ my_G\,(\dot{w} - qu + pv - q\dot{x}_G + \ddot{z}_G)$$

$$+ \dot{I}_{xx}p + \dot{I}_{xy}q + \dot{I}_{xz}r + mx_G\,(\dot{z}_G r + \dot{y}_G q) \qquad (2.3 - 25)$$

$$M = I_{yy}\dot{q} + I_{yz}\,(\dot{r} - qp) + I_{yx}\,(\dot{p} + qr) + I_{zx}\,(r^2 - p^2) + (I_{xx} - I_{zz})\,rp$$

$$- mx_G\,(\dot{w} - qu + pv + p\dot{y}_G + \ddot{z}_G)$$

$$+ mz_G\,(\dot{u} - rv + qw - r\dot{y}_G + \ddot{x}_G)$$

$$+ \dot{I}_{yy}q + \dot{I}_{yz}r + \dot{I}_{yx}p + my_G\,(\dot{x}_G p + \dot{z}_G r) \qquad (2.3 - 26)$$

$$N = I_{zz}\dot{r} + I_{zx}\,(\dot{p} - rq) + I_{zy}\,(\dot{q} + rp) + I_{xy}\,(p^2 - q^2) + (I_{yy} - I_{xx})\,pq$$

$$- my_G\,(\dot{u} - rv + qw + q\dot{z}_G + \ddot{x}_G)$$

$$+ mx_G\,(\dot{v} - pw + ru - p\dot{z}_G + \ddot{y}_G)$$

$$+ \dot{I}_{zz}r + \dot{I}_{zx}p + \dot{I}_{zy}q + mz_G\,(\dot{y}_G q + \dot{x}_G p) \qquad (2.3 - 27)$$

where I_{xx}, I_{xy} ..... are about axes through the vehicle origin. These equations also contain derivatives of the form $\dot{I}_{xx}$, $\dot{I}_{xy}$ ..... $\dot{x}_G$, $\ddot{x}_G$......

The tensor I_o can be thought of as being made up of two parts; a constant part representing the vehicle with all jettisonable ballast removed, I_1, and the jettisonable ballast, I_2, such that:

$$I_o = I_1 + I_2 \qquad (2.3 - 28)$$

The contribution of the ballast can be modeled by assuming that each weight that is part of the jettisonable ballast is lumped at its center of gravity (x_{gi}, y_{gi}, z_{gi}).

Then:

$$I_{xx,2} = \sum_{i=1}^{N} m_i (y_{gi}^2 + z_{gi}^2) \qquad (2.3 - 29)$$

$$I_{xy,2} = \sum_{i=1}^{N} m_i x_{gi} y_{gi} \qquad (2.3 - 30)$$

$$I_{xz,2} = \sum_{i=1}^{N} m_i x_{gi} z_{gi} \ldots \qquad (2.3 - 31)$$

where N is the number of weights.

I_2 is the time varying part of I_o, however, to be consistent with the quasi-steady approximation made in developing equations (2.3 - 7 through 2.3 - 9), a quasi-steady change in the inertial tensor must also be assumed. This then says that the terms involving time derivatives of the inertial tensor and the center of gravity can be dropped, since they are zero during the time interval over which the process is assumed to be steady.

The equations can be further reduced when it is recognized that,

due to the assumption of an xz plane of symmetry and a further assumption that the ballast will be dropped symmetrically, the products of inertia

$$I_{xy,1} = I_{yx,1} = I_{yz,1} = I_{zy,1} = I_{xy,2} = I_{yx,2} = I_{yz,2} = I_{zy,2} = 0$$

Thus, the total moment of inertia becomes quasi-steady and can be used in the equations of motion without 0, 1 or 2 subscripts. The final form of the dynamical equations then becomes:

$$X = m\left[\dot{u} - rv + qw - x_G (q^2 + r^2) + y_G (pq - \dot{r}) + z_G (pr + \dot{q})\right] \quad (2.3 - 32)$$

$$Y = m\left[\dot{v} - pw + ru - y_G (r^2 + p^2) + z_G (qr - \dot{p}) + x_G (qp + \dot{r})\right] \quad (2.3 - 33)$$

$$Z = m\left[\dot{w} - qu + pv - z_G (p^2 + q^2) + x_G (rp - \dot{q}) + y_G (rq + \dot{p})\right] \quad (2.3 - 34)$$

$$K = I_{xx}\dot{p} + I_{xz} (\dot{r} + pq) + (I_{zz} - I_{yy}) qr$$
$$+ m\left[- z_G (\dot{v} - pw + ru) + y_G (\dot{w} + pv - qu)\right] \quad (2.3 - 35)$$

$$M = I_{yy}\dot{q} + I_{zx} (r^2 - p^2) + (I_{xx} - I_{zz}) rp$$
$$+ m\left[- x_G (\dot{w} - qu + pv) + z_G (\dot{u} + qw - rv)\right] \quad (2.3 - 36)$$

$$N = I_{zz}\dot{r} + I_{zx} (\dot{p} - rq) + (I_{yy} - I_{xx}) pq$$
$$+ m\left[-y_G (\dot{u} - rv + qw) + x_G (\dot{v} + ru - pw)\right] \quad (2.3 - 37)$$

where m, x_G, y_G, z_G, I_{xx}, I_{yy}, I_{zz}, I_{xz} are all quasi-steady functions of time.

The forcing terms for the hydrodynamic equations are made up of

gravity forces, hydrodynamic forces and propulsion induced forces. Since the problem has been defined as a free ascent problem there will be no propulsion forces included. Because of this restriction, the experimental hydrodynamic coefficients should be obtained without propellers running. The total forcing terms are then:

$$X = X_G + X_H$$
$$Y = Y_G + Y_H$$
$$Z = Z_G + Z_H$$
$$K = K_G + K_H$$
$$M = M_G + M_H$$
$$N = N_G + N_H \qquad (2.3 - 38)$$

II - 4 Gravity Forces

The hydrostatic pressure field induced by gravity creates a buoyancy force B through the CB. This force varies with ambient water density and vehicle volume. The instantaneous weight of the body, W, acting through the CG, is made up of W_B, the weight of the body without jettisonable ballast, less W_i, the weight of the ballast components removed.

During the initial phase of the ascent the items in $\sum_{i=1}^{N} W_i$ are increased until all of the ballast components have been removed, at this point the buoyant force (-B + W) becomes a maximum, if we neglect changes in vehicle volume and density. This maximum force is sustained for the rest of the ascent.

The instantaneous buoyant force can thus be represented by:

$$- B + W - \sum_{i=1}^{N} W_i \qquad (2.4 - 1)$$

where N = the number of ballast components removed. This force acts

upwards along the local vertical. Due to the choice of origin of the body axes, the gravity induced torque is $\vec{r}_G \times \vec{B}$ where $\vec{r}_G$ is the CG position vector in body axes and $\vec{B}$ is the vehicle buoyancy vector acting up along the local vertical. Resolving along body axes the gravity forces become:

$$X_G = -(W - B) \sin \theta \qquad (2.4 - 2)$$

$$Y_G = (W - B) \cos \theta \sin \phi \qquad (2.4 - 3)$$

$$Z_G = (W - B) \cos \theta \cos \phi \qquad (2.4 - 4)$$

$$K_G = (y_G W - y_B B) \cos \theta \cos \phi - (z_G W - z_B B) \cos \theta \sin \phi \qquad (2.4 - 5)$$

$$M_G = -(x_G W - x_B B) \cos \theta \cos \phi - (z_G W - z_B B) \sin \theta \qquad (2.4 - 6)$$

$$N_G = (x_G W - x_B B) \cos \theta \sin \phi + (y_G W - y_B B) \sin \theta \qquad (2.4 - 7)$$

II - 5 Hydrodynamic Forces

The hydrodynamic forces and moments that act on a body moving through a real fluid are the result of:

(1) hydrodynamic inertial affects (linear added mass terms),

(2) skin friction, separation and cross-flow drag effects,

(3) circulation effects.

These effects are all functions of the velocities and accelerations of the body. Therefore, the hydrodynamic forces and moments can be expressed functionally as:

$$\left.\begin{matrix} F_H \\ M_H \end{matrix}\right] = f\,(u, v, w, p, q, r, \dot{u}, \dot{v}, \dot{w}, \dot{p}, \dot{q}, \dot{r}) \qquad (2.5 - 1)$$

This function may be reduced to a workable form by expanding the function in a Taylor series. Expanding the function in this form requires that the function and its derivatives be continuous in the region of the

values of the variables under consideration. A typical second order expansion of one of the force equations would be of the form:

$$
\begin{aligned}
X = X_o &+ u \frac{\partial X}{\partial u} + v \frac{\partial X}{\partial v} + \cdots\cdots\cdots + r \frac{\partial X}{\partial r} \\
&+ \dot{u} \frac{\partial X}{\partial \dot{u}} + \dot{v} \frac{\partial X}{\partial \dot{v}} + \cdots\cdots\cdots + \dot{r} \frac{\partial X}{\partial \dot{r}} \\
&+ \tfrac{1}{2} \Big(u^2 \frac{\partial^2 X}{\partial u^2} + v^2 \frac{\partial^2 X}{\partial v^2} + \cdots\cdots + r^2 \frac{\partial^2 X}{\partial r^2} \\
&+ uv \frac{\partial^2 X}{\partial u \partial v} + uw \frac{\partial^2 X}{\partial u \partial w} + \cdots\cdots + ur \frac{\partial^2 X}{\partial u \partial r} \\
&\qquad\qquad \vdots \\
&+ pq \frac{\partial^2 X}{\partial p \partial q} + pr \frac{\partial^2 X}{\partial p \partial r} + qr \frac{\partial^2 X}{\partial q \partial r} \\
&+ u\dot{u} \frac{\partial^2 X}{\partial u \partial \dot{u}} + u\dot{v} \frac{\partial^2 X}{\partial u \partial \dot{v}} + \cdots\cdots + u\dot{r} \frac{\partial^2 X}{\partial u \partial \dot{r}} \\
&\qquad\qquad \vdots \\
&+ r\dot{u} \frac{\partial^2 X}{r \, \dot{u}} + \cdots\cdots\cdots\cdots + r\dot{r} \frac{\partial^2 X}{\partial r \partial \dot{r}} \\
&+ \dot{u}\dot{u} \frac{\partial^2 X}{\partial \dot{u}^2} + \dot{v}\dot{v} \frac{\partial^2 X}{\partial \dot{v}^2} + \cdots\cdots + \dot{r}\dot{r} \frac{\partial^2 X}{\partial \dot{r}^2} \\
&\qquad\qquad \vdots \\
&+ \dot{p}\dot{q} \frac{\partial^2 X}{\partial \dot{p} \partial \dot{q}} + \cdots\cdots\cdots\cdots + \dot{q}\dot{r} \frac{\partial^2 X}{\partial \dot{q} \partial \dot{r}} \qquad (2.5 - 2)
\end{aligned}
$$

This equation contains ninety-one constant, linear and second order terms arising from the Taylor series expansion. The number of terms, however, can be reduced to thirty-three on the basis of the problem assumptions and restrictions delineated in Chapter I.

The constant term is dropped to conform with the requirement that

initially the only disturbance is due to a buoyant force which is included as a gravity term.

The terms involving products of accelerations with velocities or accelerations are dropped because the second order effects were restricted to velocities only. In addition the results of potential theory indicate that these derivatives are zero. (See ref 2)

After eliminating all but the linear terms and the second order velocity terms, the Taylor series expansions of the hydrodynamic forces and moments become of the form:

$$
\begin{aligned}
X_H = {} & X_u u + X_v v + X_w w + X_p p + X_q q + X_r r \\
& + X_{\dot{u}}\dot{u} + X_{\dot{v}}\dot{v} + X_{\dot{w}}\dot{w} + X_{\dot{p}}\dot{p} + X_{\dot{q}}\dot{q} + X_{\dot{r}}\dot{r} \\
& + X_{u^2}u^2 + X_{v^2}v^2 + X_{w^2}w^2 + X_{p^2}p^2 + X_{q^2}q^2 + X_{r^2}r^2 \\
& + X_{uv}uv + X_{uw}uw + X_{up}up + X_{uq}uq + X_{ur}ur \\
& + X_{vw}vw + X_{vp}vp + X_{vq}vq + X_{vr}vr \\
& + X_{wp}wp + X_{wq}wq + X_{wr}wr \\
& + X_{pq}pq + X_{pr}pr + X_{qr}qr \qquad (2.5 - 3)
\end{aligned}
$$

The terms in this expression are seen to fall into one of three catagories, namely:

(1) added mass or inertial,

(2) second order non-inertial,

(3) linear.

In order to further reduce the number of terms retained in each of these cat-

egories, it is necessary to look at the nature of the terms and the effect that a plane of symmetry has on them.

II - 5.1 Added Mass Terms

A body moving through a real fluid induces a motion in the otherwise stationary fluid because the fluid must move aside and then close in behind the body. As a result of this motion the fluid possesses kinetic energy that it would not possess if the body were not in motion. The added mass terms in the equations take into account the energy given to the fluid by the body.

If the body motion is steady, the related fluid motion is also steady which requires that the kinetic energy be constant. If the kinetic energy is constant, no work is being done on the fluid and therefore the added mass terms may be omitted.

If, however, the body is in accelerated motion, there will be work done by the body on the fluid and it will be necessary to retain at least some of the added mass terms.

Work is accomplished by moving a force through a distance. In the case of a submerged body, the distance is the distance the body travels and the force is the integral over the surface of the body of the pressures exerted by the body on the fluid. This force, in general, represents a system of forces and moments acting on the body which can be obtained from equations (2.3 - 1 through 6), when the kinetic energy is varied.

The kinetic energy of the fluid can be represented as a function of the six velocity components (u, v, w, p, q, r). A quadratic form of this function as given by Lamb (see page 172 ref 1) is:

$$
\begin{aligned}
2T_f = {} & Au^2 + Bv^2 + Cw^2 + 2A'vw + 2B'wu + 2C'uv \\
& + Pp^2 + Qq^2 + Rr^2 + 2P'qr + 2Q'rp + 2R'pq \\
& + 2Lup + 2M'vq + 2N'wr \\
& + 2F\ (vr + wq) + 2G\ (wp + ur) + 2H\ (uq + vp) \\
& + 2F'\ (vr - wq) + 2G'\ (wp - ur) + 2H'\ (uq - vp) \qquad (2.5 - 4)
\end{aligned}
$$

where the twenty-one coefficients A, B, C etc. are certain constants determined by the form and position of the surface relative to the co-ordinate axes.

Letting

$$
\begin{aligned}
F + F' &= F_1 & \qquad F - F' &= F_2 \\
H + H' &= H_1 & \qquad H - H' &= H_2 \\
G + G' &= G_1 & \qquad G - G' &= G_2
\end{aligned}
$$

the last six terms in (2.5 - 4) become:

$$+ 2F_1 vr + G_1 sp + 2H_1 uq$$

$$+ 2F_2 wq + G_2 ur + 2H_2 vp$$

Nine of the coefficients in the above expression may be set to zero if we take advantage of the assumed xz plane of symmetry. Symmetry arguments say that T_f should not be changed if any of the terms vw, uv, qr, pq, up, vq, wr, wp, ur is replaced respectively by (-v) w, (-v) u, (-r) q, (-p) q, (-p) u, (-v) q, (-r) w, (-p) w, (-r) u. These terms correspond respectively with the coefficients A', C', P', R', L, M', N', G, G'.

When T_f is substituted for T_v in equations (2.3 - 1 through 6), these nine coefficients can be traced to their corresponding terms in equations (2.5 - 3), at which time these terms can be eliminated from the

hydrodynamic expressions.

Six partial derivatives must be obtained from equation (2.5 - 4) in order to expand equations (2.3 - 1 through 6), these are:

$$\frac{\partial T_f}{\partial u} = Au + B'w + C'v + Lp + H_1q + G_2r \qquad (2.5 - 5)$$

$$\frac{\partial T_f}{\partial v} = Bv + A'w + C'u + M'q + F_1r + H_2p \qquad (2.5 - 6)$$

$$\frac{\partial T_f}{\partial w} = Cw + A'v + B'u + N'r + G_1p + F_2q \qquad (2.5 - 7)$$

$$\frac{\partial T_f}{\partial p} = Pp + Q'r + R'q + Lu + G_1w + H_2v \qquad (2.5 - 8)$$

$$\frac{\partial T_f}{\partial q} = Qq + P'r + R'p + M'v + H_1u + F_2w \qquad (2.5 - 9)$$

$$\frac{\partial T_f}{\partial r} = Rr + P'q + Q'p + N'w + F_1v + G_2u \qquad (2.5 - 10)$$

These derivatives are then substituted in equations (2.3 - 1 through 6) to obtain:

$$\begin{aligned} X = {} & A\dot{u} + B'\dot{w} + C'\dot{v} + L\dot{p} + H_1\dot{q} + G_2r \\ & + Cqw + A'vq + B'uq + N'rq + G_1pq + F_2qq \\ & - Bvr - A'wr - C'ur - M'qr - F_1rr - H_2pr \qquad (2.5 - 11) \end{aligned}$$

$$\begin{aligned} Y = {} & B\dot{v} + A'\dot{w} + C'\dot{u} + M'\dot{q} + F_1\dot{r} + H_2\dot{p} \\ & + Aur + B'wr + C'vr + Lpr + H_1qr + G_2rr \\ & - Cwp - A'vp - B'up - N'rp - G_1pp - F_2qp \qquad (2.5 - 12) \end{aligned}$$

$$\begin{aligned} Z = {} & C\dot{w} + A'\dot{v} + B'\dot{u} + N'\dot{r} + G\dot{p} + F_2\dot{q} \\ & + Bvp + A'wp + C'up + M'qp + F_1rp + H_2pp \\ & - Auq - B'wq - C'vq - Lpq - H_1qq - G_2rq \qquad (2.5 - 13) \end{aligned}$$

$$\begin{aligned} K = {} & P\dot{p} + Q'\dot{r} + R'\dot{q} + L\dot{u} + G_1\dot{w} + H_2\dot{v} \\ & + Rrq + P'qq + Q'pq + \acute{N}wq + F_1vq + G_2uq \\ & - Qqr - P'rr - R'pr - \acute{M}vr - H_1ur - F_2wr \\ & + Cwv + A'vv + B'uv + \acute{N}rv + G_1pv + F_2qv \\ & - B_{vw} - A'ww - C'uw - \acute{M}qw - F_1rw - H_2pw \end{aligned} \qquad (2.5 - 14)$$

$$\begin{aligned} M = {} & Q\dot{q} + P'\dot{r} + R'\dot{p} + \acute{M}\dot{v} + H_1\dot{u} + F_2\dot{w} \\ & + Ppr + Q'rr + R'qr + Lur + G_1wr + H_2vr \\ & - Rrp - P'qp - Q'pp - \acute{N}wp - F_1vp - G_2up \\ & + Auw + B'ww + C'vw + Lpw + H_1qw + G_2rw \\ & - Cwu - A'vu - B'uu - \acute{N}ru - G_1pu - F_2qu \end{aligned} \qquad (2.5 - 15)$$

$$\begin{aligned} N = {} & R\dot{r} + P'\dot{q} + \acute{N}\dot{w} + F_1\dot{v} + G_2\dot{u} \\ & + Qqp + P'rp + R'pp + \acute{M}vp + H_1up + F_2wp \\ & - Ppq - Q'rq - R'qq - Luq - G_1wq - H_2vq \\ & + Bvu + A'wu + C'uu + \acute{M}qu + F_1ru + H_2pu \\ & - Auv - B'wv - C'vv - Lpv - H_1qv - G_2rv \end{aligned} \qquad (2.5 - 16)$$

Setting the various coefficients in equations (2.5 - 11 through 16) equal to their counterparts in equations (2.5 - 3) it is found that:

$$A' = X_{vq} = -X_{wr} = Y_{\dot w} = -Y_{vp} = Z_{\dot v} = Z_{wp} = K_{vv} = -K_{ww} = -M_{vu} = N_{wu}$$

$$C' = X_{\dot v} = -X_{ur} = Y_{\dot u} = Y_{vr} = Z_{up} = -Z_{vq} = -K_{uw} = M_{vw} = N_{uu} = -N_{vv}$$

$$G_1 = X_{pq} = -Y_{pp} = Z_{\dot p} = K_{\dot w} = K_{pv} = M_{wr} = -M_{pu} = -N_{wq}$$

$$G_2 = X_{\dot r} = Y_{rr} = -Z_{rq} = K_{uq} = -M_{up} = M_{rw} = N_{\dot u} = -N_{rv}$$

$$L = X_{\dot p} = K_{\dot u} = M_{ur} = M_{pw} = -N_{uq} = -N_{pv}$$

$$M' = Y_{\dot q} = -K_{qw} = M_{\dot v} = N_{vp} = N_{qu}$$

$$N' = Z_{\dot r} = K_{wq} = -M_{wp} = -N_{ru} = N_{\dot w}$$

$$P' = K_{qq} = -K_{rr} = M_{\dot r} = M_{qr} = N_{\dot q} = N_{rp}$$

$$R' = K_{\dot q} = -K_{pr} = M_{\dot p} = -M_{qp} = N_{pp} = -N_{qq}$$

$$N' - K' = X_{qr} = K_{vr}$$

$$L - N' = Y_{pr} = M_{ru} = M_{pw}$$

$$M' - L = Z_{pq}$$

$$G_1 + G_2 = M_{rw} = -M_{pu}$$

$$M' - L = N_{vp} = N_{uq} \qquad (2.5 - 17)$$

$$H_1 + H_2 = N_{up} = -N_{vq}$$

$$B - A = N_{uv} \qquad (2.5 - 18)$$

$A = X_{\dot u} = Y_{ur} = -Z_{uq}$

$B = -X_{vr} = Y_{\dot v} = Z_{vp}$

$C = X_{qw} = -Y_{wp} = Z_{\dot w}$

$B' = X_{\dot w} = X_{uq} = Y_{wr} = -Y_{up} = Z_{\dot u} = -Z_{wq} = K_{uv} = M_{ww} = -M_{uu} = -N_{wv}$

$P = K_{\dot p} = -N_{pq}$

$Q = M_{\dot q} = N_{qp}$

$R = N_{\dot r}$

$Q' = K_{\dot r} = K_{pq} = M_{rr} = -M_{pp} = N_{\dot p} = -N_{rq}$

$F_1 = -X_{rr} = Y_{\dot r} = Z_{rp} = -M_{vp} = N_{\dot v} = N_{ru}$

$F_2 = X_{qq} = -Y_{qp} = Z_{\dot q} = M_{\dot w} = -M_{qu} = N_{vp}$

$H_1 = X_{\dot q} = Y_{qr} = -Z_{qq} = -K_{ur} = M_{\dot u} = M_{qw} = N_{up} = -N_{qv}$

$H_2 = -X_{pr} = Y_{\dot p} = Z_{pp} = K_{\dot v} = -K_{pw} = M_{vr} = -N_{vq} = N_{pu}$

$C - B = K_{wv}$

$F_1 + F_2 = -K_{wr} = K_{vq}$

$R - Q = K_{qr}$

$P - R = M_{pr}$

$A - C = M_{wu}$

$Q - P = N_{pq}$ (2.5 - 18) cont.

where equations (2.5 - 17) represent the terms which are zero due to symmetry.

Eliminating those terms which, due to the xz plane of symmetry, are zero, and using the standard nomenclature, as given in reference (6), in place of Lamb's notation, the added mass expressions become:

$$X_{Hi} = X_{\dot{u}}\dot{u} + X_{\dot{w}}\dot{w} + X_{\dot{q}}\dot{q} + X_{qw}qw + X_{uq}uq$$

$$+ X_{qq}qq + X_{vr}vr + X_{r^2}r^2 + X_{pr}pr \qquad (2.5 - 19)$$

$$Y_{Hi} = Y_{\dot{v}}\dot{v} + Y_{\dot{r}}\dot{r} + Y_{\dot{p}}\dot{p} + Y_{ur}ur + Y_{wr}wr$$

$$+ Y_{qr}qr + Y_{wp}wp + Y_{up}up + Y_{qp}qp \qquad (2.5 - 20)$$

$$Z_{Hi} = Z_{\dot{w}}\dot{w} + Z_{\dot{u}}\dot{u} + Z_{\dot{q}}\dot{q} + Z_{vp}vp + Z_{rp}rp$$

$$+ Z_{pp}pp + Z_{uq}uq + Z_{wq}wq + Z_{qq}qq \qquad (2.5 - 21)$$

$$K_{Hi} = K_{\dot{p}}\dot{p} + K_{\dot{r}}\dot{r} + K_{\dot{v}}\dot{v} + K_{rq}rq + K_{pq}pq$$

$$+ K_{vq}vq + K_{uv}uv + K_{ur}ur + K_{wr}wr$$

$$+ K_{wv}wv + K_{pw}pw \qquad (2.5 - 22)$$

$$M_{Hi} = M_{\dot{q}}\dot{q} + M_{\dot{u}}\dot{u} + M_{\dot{w}}\dot{w} + M_{rr}rr + M_{vr}vr$$

$$+ M_{rp}rp + M_{pp}pp + M_{vp}vp + M_{uw}uw$$

$$+ M_{ww}ww + M_{qw}qw + M_{uu}uu + M_{qu}qu \qquad (2.5 - 23)$$

$$N_{Hi} = N_{\dot{r}}\dot{r} + N_{\dot{p}}\dot{p} + N_{\dot{v}}\dot{v} + N_{qp}qp + N_{up}up$$

$$+ N_{wp}wp + N_{rq}rq + N_{vq}vq + N_{vu}vu$$

$$+ N_{ru}ru + N_{wv}wv \qquad (2.5 - 24)$$

The equalities given in equations (2.5 - 17 and 18) are based entirely upon potential theory and do not necessarily hold in the presence of circulation and viscous effects. If circulation and viscous effects are neglected, these equalities provide reasonably good estimates of some of the second order coefficients which are not directly amenable to measurement by conventional towing tank techniques.

II - 5.2 Second Order Terms

The second order terms which are not added mass terms are:

$$\begin{aligned} X_{H2} = {} & X_{u^2}u^2 + X_{v^2}v^2 + X_{w^2}w^2 + X_{p^2}p^2 \\ & + X_{uv}uv + X_{uw}uw + X_{up}up \\ & + X_{vw}vw + X_{vp}vp + X_{wp}wp \end{aligned} \qquad (2.5 - 25)$$

$$\begin{aligned} Y_{H2} = {} & Y_{u^2}u^2 + Y_{v^2}v^2 + Y_{w^2}w^2 + Y_{q^2}q^2 \\ & + Y_{uv}uv + Y_{uw}uw + Y_{uq}uq \\ & + Y_{vw}vw + Y_{vq}vq + Y_{wq}wq \end{aligned} \qquad (2.5 - 26)$$

$$\begin{aligned} Z_{H2} = {} & Z_{u^2}u^2 + Z_{v^2}v^2 + Z_{w^2}w^2 + Z_{r^2}r^2 \\ & + Z_{uv}uv + Z_{uw}uw + Z_{ur}ur \\ & + Z_{vw}vw + Z_{vr}vr + Z_{wr}wr \end{aligned} \qquad (2.5 - 27)$$

$$K_{H2} = K_{u^2}u^2 + K_{p^2}p^2 + K_{up}up \qquad (2.5 - 28)$$

$$M_{H2} = M_{v^2}v^2 + M_{q^2}q^2 + M_{vq}vq \qquad (2.5 - 29)$$

$$N_{H2} = N_{w^2}w^2 + N_{r^2}r^2 + N_{wr}wr \qquad (2.5 - 30)$$

The symmetry plane (xz plane) force and moment terms (X, Z, M), which involve products of the symmetry plane velocities (u, w, q) with the out of plane velocities (v, p, r) must be zero for the reason that the same force or moment must result if v, p, r are replaced by -v, -p, -r. This does not hold true with respect to products of xz plane velocities or to products of out of plane velocities.

Another symmetry argument that can be made is that a symmetry plane velocity or products of symmetry plane velocities should not cause out of the plane forces or moments. For example, there should be no Y force resulting from a w velocity or even a combination of w and u velocities.

After removing these symmetry terms from equations (2.5 - 25 through 30) the second order hydrodynamic terms left are:

$$X_{H2} = X_{u^2}u^2 + X_{v^2}v^2 + X_{w^2}w^2 + X_{p^2}p^2 + X_{uw}uw + X_{vp}vp \qquad (2.5 - 31)$$

$$Y_{H2} = Y_{v^2}v^2 + Y_{uv}uv + Y_{vw}vw + Y_{vq}vq \qquad (2.5 - 32)$$

$$Z_{H2} = Z_{u^2}u^2 + Z_{v^2}v^2 + Z_{w^2}w^2 + Z_{r^2}r^2 + Z_{uw}uw + Z_{vr}vr \qquad (2.5 - 33)$$

$$K_{H2} = K_{p^2}p^2 + K_{up}up \qquad (2.5 - 34)$$

$$M_{H2} = M_{v^2}v^2 + M_{q^2}q^2 \qquad (2.5 - 35)$$

$$N_{H2} = N_{r^2}r^2 + N_{vr}vr \qquad (2.5 - 36)$$

II - 5.3 Linear Terms

The linear terms in the hydrodynamic force equations are:

$$X_{HL} = X_u u + X_v v + X_w w + X_p p + X_q q + X_r r \qquad (2.5 - 37)$$

$$Y_{HL} = Y_u u + Y_v v + Y_w w + Y_p p + Y_q q + Y_r r \qquad (2.5 - 38)$$

$$Z_{HL} = Z_u u + Z_v v + Z_w w + Z_p p + Z_q q + Z_r r \qquad (2.5 - 39)$$

$$K_{HL} = K_u u + K_v v + K_w w + K_p p + K_q q + K_r r \qquad (2.5 - 40)$$

$$M_{HL} = M_u u + M_v v + M_w w + M_p p + M_q q + M_r r \qquad (2.5 - 41)$$

$$N_{HL} = N_u u + N_v v + N_w w + N_p p + N_q q + N_r r \qquad (2.5 - 42)$$

In order to determine which of these terms should be retained, each term must, in general be considered on its own merits. There is, however, one group of terms all of which may be eliminated on the basis of the assumed xz plane of symmetry.

The coefficients which, due to symmetry, must be zero are:

(1) those that involve derivatives of the symmetry plane forces and moment with respect to the out of plane velocities (v, p, r),

(2) the out of plane force (Y) and moments (K, N) which would arise from an in the symmetry plane velocity (u, w, q).

Those that fall in the first category are of the type which require the force or moment to stay the same while the velocity can change sign. Those of the second category would require a force perpendicular to the plane of symmetry to result from a flow in the plane of symmetry.

Eliminating these terms from the linear terms equations, results in the following:

$$X_{HL} = X_u u + X_w w + X_q q \qquad (2.5 - 43)$$

$$Y_{HL} = Y_v v + Y_p p + Y_r r \qquad (2.5 - 44)$$

$$Z_{HL} = Z_u u + Z_w w + Z_q q \qquad (2.5 - 45)$$

$$K_{HL} = K_v v + K_p p + K_r r \qquad (2.5 - 46)$$

$$M_{HL} = M_u u + M_w w + M_q q \qquad (2.5 - 47)$$

$$N_{HL} = N_v v + N_p p + N_r r \qquad (2.5 - 48)$$

II - 5.4 Discussion of Terms

The hydrodynamic force and moment equations that result after eliminating the symmetry terms will now be looked at in order to further reduce the number of terms in the equations.

Of first importance is the decision to retain all terms, or a form from which they can be derived, that are included in "The Standard Equations of Motion for Submarine Simulation" (see ref 8) that would apply to an unpropelled vehicle.

In general, the terms which are retained herein but are not retained by either NSRDC or MIT/IL are done so with the idea that not all submersibles possess the near fore and aft and symmetries that modern military submarines and the DSRV possess.

The procoedure to be followed will be to look at the terms that remain after the symmetry terms have been eliminated and the terms retained by other authors have been set aside.

Prior to looking at the individual force and moment equations, the effect of the choice of expansion point for the Taylor series should be investigated.

The most common operating point about which hydrodynamic forces and moments are expanded is some finite forward velocity. When this is done, the linear terms given by equations (2.5 - 43 through 48) exist. These terms include the effect of circulation which does not appear in the potential theory and the Munk moments which arise from the potential theory. Additionally these terms account for the effect that some finite initial velocity has upon the drag terms.

For the present study of emergency ascent trajectories, the initial operating condition is for the vehicle to be at rest in the fluid. Since the force causing the vehicle to ascend is the result of releasing ballast from any position on the vehicle, it is as likely for the vehicle to start moving astern as it is ahead. With this sort of operating condition, the most reasonable expansion point for the Taylor series is then the zero velocity condition. This, however, presents the problem of completely eliminating all the linear terms from the series expansion, since they must be evaluated at the expansion point, zero velocity. For example:

$$w\left[\frac{\partial M}{\partial w}\right]_{u = v_o} = 0 \qquad \text{since } u_o = 0$$

Dispite the elimination of the linear terms in the Taylor series expansion, we are dealing with a real fluid and the effect of circualtion will still arise as the vehicle commences to move and the potential theory still indicates that the Munk moments exist. The logical place for them to be included is, of course, in the second order terms such as M_{uw}. Therefore, in the development that follows it must be remembered, that what is

generally included as a linear effect is now part of the second order effects.

The drag effects represented by $Z_w w$, $Z_{ww} w^2$, etc. in the usual case must now be represented by only the second order terms $Z_{ww} w^2$, etc.

In the interest of developing as general a set of equations as possible, the linear terms usually appearing in the hydrodynamic equations shall be retained, though zero for this particular case.

II - 5.4.1 *Axial Force*

The axial force equation without symmetry terms is:

$$
\begin{aligned}
X_H = {} & X_{\dot u}\dot u + X_{q^2}q^2 + X_{r^2}r^2 + X_{vr}vr + X_{wq}wq + X_{pr}pr \\
& + X_{u^2}u^2 + X_{v^2}v^2 + X_{w^2}w^2 \\
& + X_{\dot w}\dot w + X_{\dot q}\dot q + X_{uq}uq + X_{uw}uw + X_{vp}vp \\
& + X_u u + X_w w + X_q q \qquad (2.5 - 49)
\end{aligned}
$$

where the first two lines represent the terms to be arbitrarily retained. The last two lines contain those terms which require further investigation before being retained or rejected.

The linear term X_u, will be dropped in favor of the non-linear X_{u^2} which equally well represents the drag phenomena. This is especially true if consideration is taken of the non-dimensionalizing parameters involved. X_u is non-dimensionalized by dividing by $(\frac{1}{2}\rho l^2 U)$ where U is, in general, the velocity of the origin of the body axes. Therefore, rather than leave the dimensions of X_u a function of velocity, we can take a further derivative with respect to u and eliminate the velocity dependence. This would then give us the alternative non-linear form indicated above.

The linear terms X_w and X_q are assumed to be zero on the basis of experimental results. (See table I of ref 2.)

The added mass terms $X_{\dot w}$, $X_{\dot q}$ and X_{uq} are greatly dependent upon the vehicle shape. If there were fore and aft symmetry there would be no axial force resulting from $X_{\dot w}$. If, however, the vehicle had a form such as ALVIN, which possess no fore and aft symmetry, there may well be forces arising from $X_{\dot w}$. Very much similar arguments can be said for $X_{\dot q}$ and X_{uq} and therefore they have been retained in the equations.

The second order term X_{uw} is assumed to be zero on the basis of experimental results (see table III of ref 2).

The one remaining coefficient X_{vp} is a second order roll transverse velocity coupling coefficient which appears to be essentially zero.

II - 5.4.2 Lateral Force

The lateral force equation without symmetry terms is:

$$\begin{aligned} Y_H = {} & Y_{\dot v}\dot v + Y_{\dot p}\dot p + Y_{\dot r}\dot r + Y_{wp}wp + Y_{wr}wr + Y_{pq}pq + Y_{qr}qr \\ & + Y_{v^2}v^2 + Y_{vq}vq + Y_{vw}vw \\ & + Y_v v + Y_p p + Y_r r \\ & + Y_{ur}ur + Y_{up}up + Y_{uv}uv \qquad (2.5 - 50) \end{aligned}$$

where the first three lines represent the terms to be arbitrarily retained.

On the basis of the potential theory developed in section II - 5.2, Y_{up} and Y_{ur} are of the order of magnitude of $X_{\dot w}$ and $X_{\dot u}$ respectively. Strumpf, in reference (2), retains these terms but notes that there is little or no experimental data available for Y_{up} while experimental results for Y_{ur} indicate that it is important.

Similarly, Y_{uv} is also believed to be of importance on the basis of experimental results cited in reference (2).

II - 5.4.3 Normal Force

The normal force equation without symmetry terms is:

$$Z_H = Z_{\dot{w}}\dot{w} + Z_{\dot{q}}\dot{q} + Z_{vp}vp + Z_{rp}rp + Z_{pp}p^2$$

$$+ Z_{vv}v^2 + Z_{ww}w^2 + Z_{rr}r^2 + Z_{vr}vr$$

$$+ Z_w w + Z_q q + Z_u u$$

$$+ Z_{\dot{u}}\dot{u} + Z_{uq}uq + Z_{wq}wq + Z_{qq}qq + Z_{uu}u^2 + Z_{uw}uw \qquad (2.5 - 51)$$

where the first three lines are the arbitrarily retained terms.

The added mass terms $Z_{\dot{u}}$, Z_{uq}, Z_{wq} and Z_{qq} are retained on the possibility of a less symmetric vehicle's giving rise to this sort of term. Potential theory estimates Z_{uq} to be of order $X_{\dot{u}}$, which is not negligible, $Z_{\dot{u}}$ and Z_{uq} to be of order $X_{\dot{w}}$, which was not neglected previously and Z_{qq} of order $X_{\dot{q}}$ according to potential theory.

The Z_{uu} term is shown to be important on the basis of experimental results (see ref 2).

II - 5.4.4 Rolling Moment

The rolling moment equation without symmetry terms is:

$$K_H = K_{\dot{p}}\dot{p} + K_{\dot{r}}\dot{r} + K_{\dot{v}}\dot{v} + K_{rq}rq + K_{pq}pq + K_{vq}vq$$

$$+ K_{wr}wr + K_{wv}wv + K_{wp}wp + K_{p^2}p^2$$

$$+ K_v v + K_p p + K_r r$$

$$+ K_{uv}uv + K_{ur}ur + K_{up}up \qquad (2.5 - 52)$$

where the first three lines represent the arbitrarily retained terms.

Here again there is little or no experimental evidence available from which estimates of K_{uv}, K_{ur} and K_{up} may be made. Potential theory indicates that these terms are small and, therefore, these terms are neglected.

II - 5.4.5 Pitching Moment

The pitching moment equation without symmetry terms is:

$$M_H = M_{\dot{q}}\dot{q} + M_{\dot{w}}\dot{w} + M_{rr}r^2 + M_{vr}vr + M_{rp}rp + M_{pp}p^2 + M_{vp}vp$$

$$+ M_{ww}w^2 + M_{wq}wq + M_{uu}u^2$$

$$+ M_{vv}v^2 + M_{qq}q^2 + M_w w + M_q q + M_u u$$

$$+ M_{\dot{u}}\dot{u} + M_{uw}uw + M_{uq}uq \qquad (2.5 - 53)$$

where the first three lines contain the arbitrarily retained terms.

Equations (2.5 - 18) show that the added mass term $M_{\dot{u}}$ is of the same size as $X_{\dot{q}}$ and M_{qw} which have been retained. Similarly M_{uq} is of the same size as $M_{\dot{w}}$. Experimental evidence cited by Strumpf supports the retention of M_{uq}.

The term M_{uw} is, in accordance with equations (2.5 - 18), equal to $(X_{\dot{u}} - Z_{\dot{w}})$. For most vehicles the $Z_{\dot{w}}$ term is considerably larger than $X_{\dot{u}}$ and therefore the term M_{uw} should be retained.

II - 5.4.6 Yawing Moment

The yawing moment equation without symmetry terms is:

$$N_H = N_{\dot{r}}\dot{r} + N_{\dot{p}}\dot{p} + N_{\dot{v}}\dot{v} + N_{pq}pq + N_{wp}wp + N_{rq}rq$$

$$+ N_{wv}wv + N_{vq}vq + N_{vv}v^2$$

$$+ N_{rr}r^2 + N_{wr}wr$$

$$+ N_v v + N_p p + N_r r$$

$$+ N_{up}up + N_{vu}vu + N_{ru}ru \qquad (2.5 - 54)$$

where the first four lines contain the terms arbitrarily retained.

Equations (2.5 - 18) show that N_{vu} is equal to $Y_{\dot{v}} - X_{\dot{u}}$, $N_{up} = N_{vq}$ and $N_{ru} = N_{\dot{v}}$. Since $Y_{\dot{v}}$ is of order of magnitude larger than $X_{\dot{u}}$, N_{vu} is of order of magnitude larger than $X_{\dot{u}}$, N_{vu} is of order $Y_{\dot{v}}$ and not negligible. $N_{\dot{v}}$ and N_{vq} and retained by the other authors and therefore, N_{up} and N_{ru} should also be retained in order to be consistent.

II - 6 Equations of Motion for Free Ascent

The conservation of momentum equations, equations (2.3 - 32 through 37), as derived in section II - 3, the gravity forces, equations (2.4 - 2 through 2.4 - 7) from section II - 4 and the hydrodynamic force equations developed in section II - 5 will now be combined to give the final form for the equations of motion for submersibles in six degrees of freedom with varying mass and center of mass.

Several of the terms retained are not generally found in most developments because the terms are not experimentally or analytically obtained by present methods.

As it is not the purpose of this paper to evaluate additional terms for the equations, these additional terms will be retained but set to zero in the computation of ascent trajectories.

The equations of motion for a vehicle with varying mass will be presented in the following manner: the left hand side of the equation represents the rigid body dynamics, the right hand side represents the hydrodynamic forces and moments acting on the body and causing the motions.

The hydrodynamic terms presented here have been non-dimensionalized in the usual manner as described in reference (6). Typical non-dimensional forms of the hydrodynamic terms are presented in the nomenclature.

For simplicity, the primes have been omitted from the terms in the equations presented.

The equations of motion for a freely ascending vehicle with variable mass are:

AXIAL FORCE

$$m \left[\dot{u} - rv + qw - x_G (q^2 + r^2) + y_G (pq - \dot{r}) + z_G (pr + \dot{q}) \right] =$$

$$\frac{\rho}{2} l^2 (X_{uu} u^2 + X_{vv} v^2 + X_{ww} w^2)$$

$$+ \frac{\rho}{2} l^3 (X_{\dot{u}} \dot{u} + X_{\dot{w}} \dot{w} + X_{uq} uq + X_{vr} vr + X_{wq} wq)$$

$$+ \frac{\rho}{2} l^4 (X_{qq} q^2 + X_{rr} r^2 + X_{rp} rp + X_{\dot{q}} \dot{q})$$

$$- (W - B) \sin \theta \, . \qquad (2.6 - 1)$$

LATERAL FORCE

$$m \left[\dot{v} - pw + ru - y_G (r^2 + p^2) + z_G (qr - \dot{p}) + x_G (qp + \dot{r}) \right] =$$

$$\frac{\rho}{2} l^2 (Y_{vv} v^2 + Y_v uv + Y_{\upsilon v} uv + Y_{vw} vw)$$

$$+ \frac{\rho}{2} l^3 (Y_{\dot{v}} \dot{v} + Y_{ur} ur + Y_r ur + Y_{vq} vq)$$

$$+ \frac{\rho}{2} l^3 (Y_{up} up + Y_p up + Y_{wp} wp + Y_{vr} wr)$$

$$+ \frac{\rho}{2} l^4 (Y_{\dot{p}} \dot{p} + Y_{\dot{r}} \dot{r} + Y_{pq} pq + Y_{qr} qr)$$

$$+ (W - B) \sin \phi \cos \theta \qquad (2.6 - 2)$$

NORMAL FORCE

$$m\left[\dot{w} - qu + pv - z_G\,(p^2 + q^2) + x_G\,(rp - \dot{q}) + y_G\,(rq + \dot{p})\right] =$$

$$\frac{\rho}{2}\,l^2\,(Z_u uu + Z_{uu}u^2 + Z_{vv}v^2 + Z_{ww}w^2 + Z_w uw + Z_{uw}uw)$$

$$+ \frac{\rho}{2}\,l^3\,(Z_{\dot{u}}\dot{u} + Z_{\dot{w}}\dot{w} + Z_{vp}vp + Z_{vr}vr + Z_q uq + Z_{wq}wq)$$

$$+ \frac{\rho}{2}\,l^4\,(Z_{\dot{q}}\dot{q} + Z_{pp}p^2 + Z_{qq}q^2 + Z_{rr}r^2 + Z_{rp}rp)$$

$$+ (W - B)\cos\theta\cos\phi \qquad (2.6 - 3)$$

ROLLING MOMENT

$$I_{xx}\dot{p} + I_{xz}\,(\dot{r} + pq) + (I_{zz} - I_{yy})\,qr$$

$$+ m\left[y_G\,(\dot{w} + pv - qu) - z_G\,(\dot{v} + ru - pw)\right] =$$

$$\frac{\rho}{2}\,l^3\,(K_{vv}v^2 + K_v uv + K_{vw}vw)$$

$$+ \frac{\rho}{2}\,l^4\,(K_{\dot{v}}\dot{v} + K_p up + K_r ur + K_{vq}vq + K_{wp}wp + K_{wr}wr)$$

$$+ \frac{\rho}{2}\,l^5\,(K_{\dot{p}}\dot{p} + K_{\dot{r}}\dot{r} + K_{pp}p^2 + K_{pq}pq + K_{qr}qr)$$

$$+ (y_G W - y_B B)\cos\theta\cos\phi - (z_G W - z_B B)\cos\theta\sin\phi$$

$$(2.6 - 4)$$

PITCHING MOMENT

$$I_{yy}\dot{q} + I_{xz}(r^2 + p^2) + (I_{xx} - I_{zz})\,rp$$

$$+ m\left[z_G(\dot{u} + qw - rv) - x_G(\dot{w} + pv - qu)\right] =$$

$$\frac{\rho}{2} l^3 (M_{uu}u^2 + M_u u^2 + M_{vv}v^2 + M_{ww}w^2 + M_{uw}uw + M_w uw)$$

$$+ \frac{\rho}{2} l^4 (M_{\dot{u}}\dot{u} + M_{\dot{w}}\dot{w} + M_{vp}vp + M_{vr}vr + M_{wq}wq)$$

$$+ \frac{\rho}{2} l^4 (M_q uq + M_{uq}uq)$$

$$+ \frac{\rho}{2} l^5 (M_{\dot{q}}\dot{q} + M_{pp}p^2 + M_{qq}q^2 + M_{rr}r^2 + M_{rp}rp)$$

$$- (x_G W - x_B B)\cos\theta\cos\phi - (z_G W - z_B B)\sin\theta \qquad (2.6 - 5)$$

YAWING MOMENT

$$I_{zz}\dot{r} + I_{xz}(\dot{p} + rq) + (I_{yy} - I_{xx})\,pq$$

$$+ m\left[x_G(\dot{v} + ru - pw) - y_G(\dot{u} + qw - rv)\right] =$$

$$\frac{\rho}{2} l^3 (N_{vv}v^2 + N_v uv + N_{uv}uv + N_{vw}vw$$

$$+ \frac{\rho}{2} l^4 (N_{\dot{v}}\dot{v} + N_{wr}wr + N_{wp}wp + N_r ur + N_{ur}ur)$$

$$+ \frac{\rho}{2} l^4 (N_{up}up + N_p up + N_{vq}vq)$$

$$+ \frac{\rho}{2} l^5 (N_{\dot{p}}\dot{p} + N_{\dot{r}}\dot{r} + N_{rr}r^2 + N_{pq}pq + N_{qr}qr$$

$$+ (x_G W - x_B B)\cos\theta\sin\phi + (y_G W - y_B B)\sin\theta \qquad (2.6 - 6)$$

II - 7 Summary

The axis systems to be used in the problem are discussed and the transformations from the earth fixed to the body fixed axes are developed.

A derivation of the dynamical equations for a vehicle with a varying mass and center of mass is then made using a Lagrangian formalism. An assumption that the reduction in mass due to releasing ballast can be represented as a quasi-steady process is discussed.

The forces acting on the body are then developed by expanding a functional representation of the forces in a Taylor series. The terms in the series are then discussed.

The equations are then non-dimensionalized for final presentation.

CHAPTER III

SOLUTION OF THE EQUATIONS OF MOTION

In the previous chapter a system of equations of motion were developed for which a solution must be found in order to obtain the ascent trajectory of a vehicle. It is possible that an analytic solution to this set of simultaneous non-linear differential equations could be found, however, it is much more practical to assume that a stepwise linear approximation to these equations. This approach has been used in many simulation studies of which the DSRV control system simulation (see ref 5) and determining the effect of hull shape non-linearities (see ref 4) are just two.

The equations as developed in Chapter II conform to the notation used by Strumpf (see ref 2) which does not conform with either the hydrodynamic terms format used by the MIT Instrumentation Laboratory for the DSRV control system studies and simulation (see ref 5), or the standard equations of motion for submarine simulation as used by NSRDC (see ref 8). In order that available hydrodynamic coefficients be utilized, the notation of Chapter II will be modified in this chapter to conform with that of the NSRDC equations. The choice of the NSRDC form over the MIT/IL form was made for the reason that it is more likely that vehicle coefficients will be obtained from NSRDC than from MIT/IL which must also get its data from other sources. The MIT/IL notation does possess the advantage of having the dimensional forms of the coefficients independent of velocity.

Before a stepwise solution to the equations can be obtained, the equations must be put into a form which is amenable to this technique.

III - 1 Revised Equations of Motion

The vehicle equations of motion are generally expressed in the form:

$$m \frac{d\vec{V}}{dt} = - m \left(\frac{d\vec{W}}{dt} \times \overrightarrow{BG} + \vec{W} \times (\vec{V} + \vec{W} \times \overrightarrow{BG})\right) + \vec{F}_{HYD} + \vec{F}_{EFF} \qquad (3.1 - 1)$$

$$\overset{*}{I} \frac{d\vec{W}}{dt} = - \vec{W} \times \overset{*}{I}\vec{W} - m\overrightarrow{BG} \times \left(\frac{d\vec{V}}{dt} + \vec{W} \times \vec{V}\right) + \vec{M}_{HYD} + \vec{M}_{EFF} \qquad (3.1 - 2)$$

where $\frac{d\vec{V}}{dt} = \dot{u}, \dot{v}, \dot{w}$, $\frac{d\vec{W}}{dt} = \dot{p}, \dot{q}, \dot{r}$ and $\overset{*}{I}$ is the inertial tensor.

To determine ascent trajectories in a stepwise linear fashion on a digital computer it is useful to rearrange the above equations so that all the derivatives are on the left side of the equations. The resulting equations are of the form:

$$\frac{d\vec{V}'}{dt} = - m\vec{W} \times (\vec{V} + \vec{W} \times \overrightarrow{BG}) + \vec{F}_{HYD} + \vec{F}_{EFF} \qquad (3.1 - 3)$$

$$\frac{d\vec{W}'}{dt} = - \vec{W} \times \overset{*}{I}\vec{W} - m\overrightarrow{BG} \times (\vec{W} \times \vec{V}) + \overrightarrow{BG} \times \vec{W}_V + \vec{M}_{HYD} + \vec{M}_{EFF} \qquad (3.1 - 4)$$

where

$$\begin{bmatrix} \frac{d\vec{V}'}{dt} \\ \\ \\ \frac{d\vec{W}'}{dt} \end{bmatrix} = [M] \begin{bmatrix} \frac{d\vec{V}}{dt} \\ \\ \\ \frac{d\vec{W}}{dt} \end{bmatrix} \qquad (3.1 - 5)$$

and $[M]$ is the six by six derivative coefficient matrix given on page 48.

$$\begin{bmatrix} m - X_{\dot{u}} & 0 & X_{\dot{w}} & 0 & mz_G - X_{\dot{q}} & - my_G \\ 0 & m - Y_{\dot{v}} & 0 & - mz_G - Y_{\dot{p}} & 0 & mx_G - Y_{\dot{r}} \\ Z_{\dot{u}} & 0 & m - Z_{\dot{w}} & my_G & - mx_G - Z_{\dot{q}} & 0 \\ 0 & - mz_G - K_{\dot{v}} & my_G & I_{xx} - K_{\dot{p}} & 0 & I_{xz} - K_{\dot{r}} \\ mz_G - M_{\dot{u}} & 0 & - mx_G - M_{\dot{w}} & 0 & I_{yy} - M_{\dot{q}} & 0 \\ - my_G & mx_G - N_{\dot{v}} & 0 & I_{xz} - N_{\dot{p}} & 0 & I_{zz} - N_{\dot{r}} \end{bmatrix}$$

Derivative Coefficient Matrix

The actual derivatives $\frac{dV}{dt}$ and $\frac{dW}{dt}$ are obtained from:

$$\begin{bmatrix} \frac{d\vec{V}}{dt} \\ \\ \frac{d\vec{W}}{dt} \end{bmatrix} = \left[M\right]^{-1} \begin{bmatrix} \frac{d\vec{V}'}{dt} \\ \\ \frac{d\vec{W}'}{dt} \end{bmatrix} \qquad (3.1 - 6)$$

where $\left[M\right]^{-1}$ is the inverse of $\left[M\right]$.

The equations to be solved for $\frac{dV'}{dt}$ and $\frac{dW'}{dt}$ are then given by the following:

$$\begin{aligned} \frac{du'}{dt} = & - m \left[- rv + qw - x_G (q^2 + r^2) + y_G pq + z_G pr \right] \\ & + \frac{\rho}{2} l^2 (X_{uu} u^2 + X_{vv} v^2 + X_{ww} w^2) \\ & + \frac{\rho}{2} l^3 (X_{uq} uq + X_{vr} vr + X_{wq} wq) \\ & + \frac{\rho}{2} l^4 (X_{qq} q^2 + X_{rr} r^2 + X_{rp} rp) \\ & - (W - B) \sin \theta + X_{EFF} \qquad (3.1 - 7) \end{aligned}$$

$$\begin{aligned} \frac{dv'}{dt} = & - m \left[- pw + ru - y_G (r^2 + p^2) + z_G qr + x_G qp \right] \\ & + \frac{\rho}{2} l^2 (Y_{v|v|} v \left| (v^2 + w^2)^{\frac{1}{2}} \right| + Y_v uv + Y_{vw} vw + Y_{*} u^2) \\ & + \frac{\rho}{2} l^3 (Y_p up + Y_r ur + Y_{vq} vq + Y_{wp} wp + Y_{wr} wr) \\ & + \frac{\rho}{2} l^3 (Y_{v|r|} \frac{v}{|v|} \left| (v^2 + w^2)^{\frac{1}{2}} \right| |r|) \\ & + \frac{\rho}{2} l^4 (Y_{pq} pq + Y_{qr} qr) + (W - B) \sin \phi \cos \theta + Y_{EFF} \end{aligned}$$

(3.1 - 8)

$$\frac{dw'}{dt} = - m \left[- qu + pv - z_G (p^2 + q^2) + x_G rp + y_G rq \right]$$

$$+ \frac{\rho}{2} l^2 (Z_u uu + Z_{vv} v^2 + Z_{w|w|} w \left| (v^2 + w^2)^{\frac{1}{2}} \right| + Z_w uw)$$

$$+ \frac{\rho}{2} l^2 (Z_{|w|} u|w| + Z_{ww} w \left| (v^2 + w^2)^{\frac{1}{2}} \right|)$$

$$+ \frac{\rho}{2} l^3 (Z_{vp} vp + Z_{vr} vr + Z_q uq + Z_{w|q|} \frac{w}{|w|} \left| (v^2 + w^2)^{\frac{1}{2}} \right| |q|)$$

$$+ \frac{\rho}{2} l^4 (Z_{pp} p^2 + Z_{qq} q^2 + Z_{rr} r^2 + Z_{rp} rp)$$

$$+ (W - B) \cos \theta \cos \phi + Z_{EFF} \qquad (3.1 - 9)$$

$$\frac{dp'}{dt} = - I_{xz} pq + (I_{yy} - I_{zz}) qr - m \left[- z_G (- pw + rq) + y_G (pv - qu) \right]$$

$$+ \frac{\rho}{2} l^3 (K_{v|v|} v \left| (v^2 + w^2)^{\frac{1}{2}} \right| + K_v uv + K_{vw} vw + K_{*} u^2)$$

$$+ \frac{\rho}{2} l^4 (K_p up + K_r ur + K_{vq} vq + K_{wp} wp + K_{wr} wr)$$

$$+ \frac{\rho}{2} l^5 (K_{p|p|} p|p| + K_{pq} pq + K_{qr} qr)$$

$$+ (y_G W - y_B B) \cos \theta \cos \phi - (z_G W - z_B B) \cos \theta \sin \phi + K_{EFF}$$

$$(3.1 - 10)$$

$$\frac{dq}{dt} = - I_{xz} (r^2 - p^2) + (I_{zz} - I_{xx}) rp$$

$$- m \left[-x_G (-qu + pv) + z_G (qw - rv) \right]$$

$$+ \frac{\rho}{2} l^3 \left(M_u u^2 + M_{vv} v^2 + M_{v|w|} v \left| (v^2 + w^2)^{\frac{1}{2}} \right| + M_w uw \right)$$

$$+ \frac{\rho}{2} l^3 \left(M_{vw} \left| v (v^2 + w^2)^{\frac{1}{2}} \right| + M_{|w|} u|w| \right)$$

$$+ \frac{\rho}{2} l^4 \left(M_{vp} vp + M_{vr} vr + M_q uq + M_{|w|q} \left| (v^2 + w^2)^{\frac{1}{2}} \right| q \right)$$

$$+ \frac{\rho}{2} l^5 \left(M_{pp} p^2 + M_{q|q|} q|q| + M_{rr} r^2 + M_{rp} rp \right)$$

$$- (x_G W - x_B B) \cos \theta \cos \phi - (z_G W - z_B B) \sin \theta + M_{EFF}$$

(3.1 - 11)

$$\frac{dr}{dt} = - I_{zx} rq + (I_{xx} - I_{yy}) pq - m \left[- y_G (-rv + qw) + x_G (ru - pw) \right]$$

$$+ \frac{\rho}{2} l^3 \left(N_{v|v|} v \left| (v^2 + w^2)^{\frac{1}{2}} \right| + N_{vw} vw + N_v uv + N_* u^2 \right)$$

$$+ \frac{\rho}{2} l^4 \left(N_{wr} wr + N_{wp} wp + N_{vq} vq \right)$$

$$+ \frac{\rho}{2} l^4 \left(N_r ur + N_{|v|r} \left| (v^2 + w^2)^{\frac{1}{2}} \right| r + N_p up \right)$$

$$+ \frac{\rho}{2} l^5 \left(N_{r|r|} r|r| + N_{pq} pq + N_{qr} qr \right)$$

$$+ (x_G W - x_B B) \cos \theta \sin \phi + (y_G W - y_B B) \sin \theta + N_{EFF}$$

(3.1 - 12)

In these equations, unlike equations (2.6 - 1 through 7) from which they come, the linear terms Y_v, Y_p, Y_r, Z_u, Z_w, M_u, M_w, M_q, N_v, N_p and N_r are combined with the non-linear terms Y_{uv}, Y_{up}, Y_{ur}, Z_{uu}, Z_{uw}, M_{uu}, M_{uw}, M_{uq}, N_{uv}, N_{up}, N_{ur}. This is done for the reason that these terms are

inseparable from a model test data reduction viewpoint. The terms $Z_{|w|}$, Z_{ww}, $M_{|w|}$ and M_{ww} have been added so as to include all of the NSRDC coefficients. The terms X_{EFF}, Y_{EFF}, Z_{EFF}, K_{EFF}, M_{EFF} and N_{EFF} have been included in order to allow for the possibility of there being some small effector forces on the vehicle. This inclusion in no way affects the legitimacy of the equations so long as the force does not cause the predominance of one velocity component .

With the equations in this form, a stepwise linear solution can be developed which will be capable of being programmed for use on a high speed digital computer.

III - 2 Stepwise Linear Solution

A stepwise linear solution is one in which the accelerations are taken as constant over a given time interval. The accelerations that exist over a time interval are determined from the velocities that existed at the end of the previous time interval and the total weight removed from the vehicle. Thus, the right hand side of equations (3.1 - 3 and 3.1 - 4) can be determined at the beginning of each time step. The inertia terms in $\left[M\right]$ must also be recomputed before each step since the mass is changing in a stepwise linear fashion as described in section II - 3. With the foregoing information equation (3.1 - 6) can be solved for the body axes accelerations.

The velocity of the vehicle in the body axis system may then be found by:

$$\begin{bmatrix} \vec{V} \\ \\ \\ \vec{W} \end{bmatrix}_t = \int_{t_0}^{t} \begin{bmatrix} \dot{\vec{V}} \\ \\ \\ \dot{\vec{W}} \end{bmatrix} dt \qquad (3.2 - 1)$$

where t_o is the time at which the ascent started and t is the present time. The integral may, however, be represented as a sum of integrals over each step in the stepwise solution. Thus:

$$\begin{bmatrix} \vec{V} \\ \\ \vec{W} \end{bmatrix}_{t_n} = \sum_{n=1}^{N} \int_{t_{n-1}}^{t_n} \begin{bmatrix} \dot{\vec{V}} \\ \\ \dot{\vec{W}} \end{bmatrix}_{t_{n-1}} dt \qquad (3.2 - 2)$$

where t_{n-1} and t_n are respectively the times at the beginning and end of the interval. The solution has been specified as stepwise linear and the accelerations are to be obtained as constants for the duration of an interval, therefore, the accelerations can be removed from the integral leaving only the trivial integration of dt from t_{n-1} to t_n. Defining Δt as $t_n - t_{n-1}$, equation (3.2 - 2) becomes:

$$\begin{bmatrix} \vec{V} \\ \\ \vec{U} \end{bmatrix}_{t_n} = \sum_{n=1}^{N} \begin{bmatrix} \dot{\vec{V}} \\ \\ \dot{\vec{W}} \end{bmatrix}_{t_{n-1}} \Delta t \quad , \qquad (3.2 - 3)$$

which gives the translational and rotational velocities of the vehicle in the body axis system.

In order to obtain the actual position of the vehicle relative to its inertial starting point the velocities obtained above must be transformed into the inertial axis system by use of the inverse of the transformation matrixes developed in section II - 2.3. The velocities $\dot{x}$, $\dot{y}$, $\dot{z}$, $\dot{\phi}$, $\dot{\theta}$, $\dot{\gamma}$ are obtained from:

$$\begin{bmatrix} \dot{x}_E \\ \dot{y}_E \\ \dot{z}_E \end{bmatrix} = T_B^{-1} \begin{bmatrix} u \\ v \\ w \end{bmatrix} ; \quad \begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} = A^{-1} \begin{bmatrix} p \\ q \\ r \end{bmatrix} \qquad (3.2-4); \ (3.2-5)$$

The position and orientation in the inertial axis system is then determined by integrating the respective velocities from t_o to t. Here again the solution is stepwise and may be represented as a sum of the individual steps. In this case, however, the integrand $\dot{x}_E$, $\dot{y}_E$, etc. is not a constant. It is, instead, a linear function of time since the acceleration from whence it came is a constant. Therefore the equation describing the vehicle trajectory and orientation becomes:

$$\begin{bmatrix} \vec{x}_E \\ \\ \vec{\phi} \end{bmatrix}_t = \sum_{n=1}^{N} \frac{1}{2} \left(\begin{bmatrix} \dot{\vec{x}}_E \\ \\ \dot{\vec{\phi}} \end{bmatrix}_{t_{n-1}} + \begin{bmatrix} \dot{\vec{x}}_E \\ \\ \dot{\vec{\phi}} \end{bmatrix}_{t_n} \right) \Delta t \qquad (3.2-6)$$

where $x_E = (x_E, y_E, z_E)$ and $\phi = (\phi, \theta, \psi)$.

The computation of x_E and ϕ are the final computations of the step. The procedure is then repeated until some maximum time is reached or some predefined position is reached.

In order to verify the result obtained by the foregoing procedure, and independent trajectory determination must be made.

III - 3 One Dimensional Ascent Trajectory

Now that a three dimensional second order method of determining free ascent trajectories has been obtained, some check on the results of this procedure is in order. The most logical approach is to reduce the problem to one in the vertical plane only and thereby reducing the complexity of the problem. If a derivation of the equations of motion were

made at this point the resulting equations would be no different from those previously obtained except that some of the coefficients would now be zero. In addition, the solution of the two dimensional equations for a complete trajectory would require the aid of a high speed digital computer.

To avoid the necessity of employing a computer, a simplified method described by Giddings and Louis in reference (9) will be used. This method, as applied to the problem under consideration, reduces to a one dimensional solution of the equations of motion for a vehicle with varying mass.

The one dimensional solution determines the vertical position, velocity and acceleration of the vehicle during its ascent. This information provides a sufficient check of the results of the computer solution of the equations of motion developed in Chapter II. A description of the one dimensional solution follows.

Defining:

B - the net buoyant force

b - the time rate of change of B

F - the sum of all forces in the vertical direction

g - the acceleration due to gravity

k - the virtual mass coefficient

m' - the mass of the vehicle plus the virtual mass

W - the instantaneous vehicle weight

z, $\dot{z}$, $\ddot{z}$ - the vertical displacement, velocity and acceleration respectively

Z_{ww}, $Z_{\dot{w}}$ - the crossflow drag and added mass coefficients respectively

Newtons laws of motion can be expressed as:

$$F = m'\ddot{z} \tag{3.3 - 1}$$

The force F is made up of the weight of the jettisoned ballast, B, plus or minus the hull drag, D, depending on the direction of motion. The force due to the jettisonning of ballast is given by:

$$B = \int_{0}^{t} b\,(t)\,dt \tag{3.3 - 2}$$

Letting the integral be represented by a series of finite steps the buoyant force becomes:

$$B = \sum_{n=1}^{N} b_n \tag{3.3 - 3}$$

where the b_n are a sequence of finite weights to be jettisonned and n is the number of intervals ellapsed since time zero.

The force due to hull drag is represented by:

$$D = \tfrac{1}{2}\rho\, l^2\, Z_{ww}\, \dot{z}\,|\dot{z}| \tag{3.3 - 4}$$

The mass, m', of the vehicle can be written as:

$$m' = \frac{W}{g}\, k \tag{3.3 - 5}$$

where $$k = \left[Z_{\dot{w}} \left(\tfrac{1}{2}\rho\, l^3\right) / (W/g) \right] + 1 \tag{3.3 - 6}$$

Substituting these expressions into equation (3.3 - 1) the equation of motion becomes:

$$\left(Z_{\dot{w}}\left(\tfrac{1}{2}\rho l^{3}\right) + \frac{W}{g}\right)\ddot{z} - Z_{ww}\left(\tfrac{1}{2}\rho l^{2}\right)\dot{z}|\dot{z}| - \sum_{n=1}^{N} b_{n} = 0 \quad (3.3 - 7)$$

The technique of step by step integration similar to that used in section III - 2 may now be applied to this equation in order to obtain the one dimensional trajectory.

III - 4 Summary

The notation and terms format to be used in the computer simulation is discussed. The notation used in the equations of motion is modified to conform with that of NSRDC and the equations are rearranged for digital computer solution.

A solution method is developed utilizing a stepwise linear technique. It accepts the vehicle velocities, position, orientation and buoyancy as initial conditions and using equations (3.1 - 6 through 3.1 - 12) it computes the accelerations, velocities, and displacements of the vehicle after a time interval Δt. Before each step the weight, CG, mass and moments of inertia are adjusted.

Finally a simplified one dimensional method is devised for comparison with the computer results.

CHAPTER IV

RESULTS AND CONCLUSIONS

In Chapter II the equations of motion were derived for a freely ascending vehicle with varying mass and center of mass. A stepwise linear solution suitable for programming on a digital computer was developed in Chapter III, and the actual program is presented in Appendix A. An equation for a one dimensional ascent trajectory was also developed in Chapter II to provide a check for the three dimensional, six degree of freedom, ascent trajectories program. A program to solve this non-linear differential equation is presented in Appendix B.

In this chpater, the computer simulations and results of these simulations are discussed, conclusions drawn and recommendations for future work in this area made.

IV - 1 Results of Computer Simulations

Computer simulations of the ascent trajectories for a vehicle similar to the Deep Submergence Rescue Vehicle were conducted using the IBM 360 computer of the MIT Information Processing Center. These simulations were conducted primarily for the purpose of debugging the ascent trajectories program and determining its operating characteristics and secondarily to study the motion tendancies of the DSRV.

IV - 1.1 Program Operating Characteristics

The ascent trajectories program in calculating the vehicle trajectories depends upon the assumed time increment for its accuracy. In general, the time increment assumed can be classed as either too large, too small or all right. Note that the latter category was "all right" not "just right".

The matter of just the right increment requires a discussion of the factors influencing the situation and, therefore, the former categories will be dealt with first.

Should the time increment chosen be too large, the forces acting on the vehicle will not be damped in a natural fashion. A vehicle under the influence of a steady force will continue to accelerate until this force is overcome by another force, and the computer does not see another force until the present time increment ends and the forces resulting from the present motion can be calculated. If the time increment is too long, the motions calculated by the computer become excessive. The eventual result is that the computer run is prematurely terminated. The actual cause of termination can be either program caused or machine caused.

A run is terminated by the program if either the time limit or the depth limit is exceeded. Since reaching the time limit or reaching the depth limit in a natural fashion do not constitute being premature, they are not considered here. The depth limit can, however, be reached in an unnatural fashion as is indicated in Appendix C, section C - 3.

A run is terminated by the computer if the number of extreme value calculations becomes excessive.

Termination for the latter cause occurs before the normal output can be made and, therefore, the only printed output received will be the initial condition printout. Termination for the former cause results in all normal output being printed.

When the time increment assumed is too small the computer round off error dominates the actual calculations and the output is meaningless.

This then leaves us with the category of the time increment being "all right". Factors which effect or are effected by the time increment in-

clude ballast removal rate, vehicular velocities and accelerations, and vehiclular stability both static and dynamic.

The ballast release rate in pounds per second (real time) can be assumed to be fixed for a given vehicle since, in emergency conditions, all ballast will, in general, be released at as high a rate as possible. Even if this is not done the ballast release rate would normally be specified and not left to the needs of the simulation. Further, the program in no way affects the ballast release rate.

The velocities and accelerations, on the other hand are directly affected by the time increment used. The change in velocity is determined by assuming that the acceleration is constant over the time period and is, therefore, equal to the product of the time increment and the acceleration. The acceleration existing during a time increment is dependent upon the forces acting on the body during that increment. The hydrodynamic forces are, in turn, dependent upon the velocities computed during the previous increment. This interdependence of forces, accelerations and velocities can be the cause of premature termination if the time increment is too large. For instance, a large increment would cause the acceleration to act for too long causing the velocity to be excessive, which in turn would cause the forces in the next increment to be excessive, etc....

The static stability of the vehicle is dependent only upon the shift of the CG relative to the CB, and is, therfore, a function of the ballast release rate only. The dynamic stability is, however, dependent upon the vehicular velocities and accelerations as well as the change in mass caused by the reduction in weight.

The essence of this discussion is that, the time increment to be used for a vehicle in free ascent will be dictated by a combination of the

ballast release rate and the expected accelerations. The ballast release rate will indicate the order of magnitude and the accelerations will refine the increment.

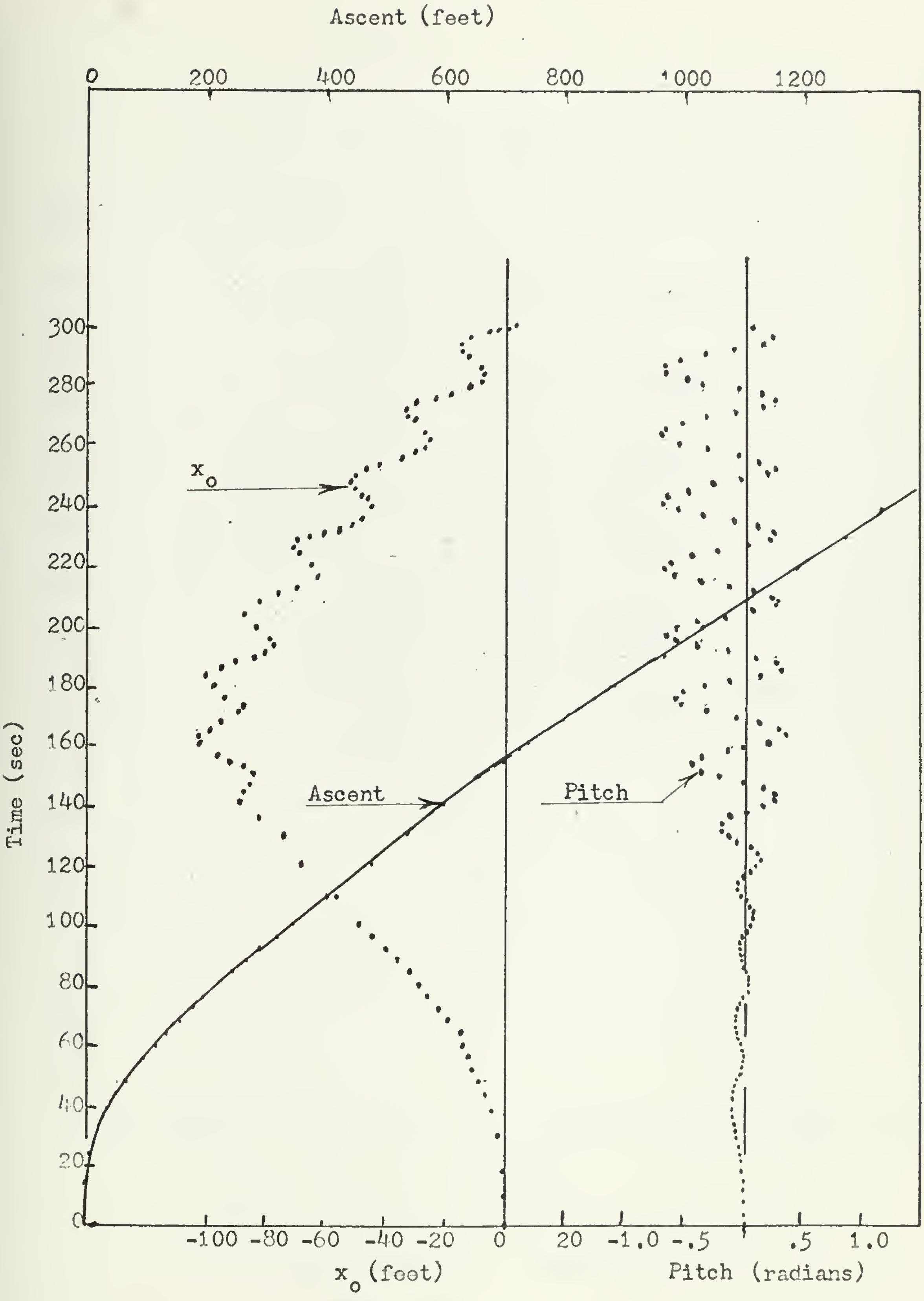
With the proper time increments chosen trajectories can be computed for a variety of initial conditions.

IV - 1.2 DSRV Motion Tendencies

The ascent trajectories generated by the ascent program are not those that would be followed by the DSRV, since the coefficients used in the program come from DSRV model tests with the propeller running. They do, however, provide an indication of the ascent trajectories and motion tendancies of that vehicle. Simulations were made with the body axes initially coincident with the inertial axes and with an initial roll angle imposed.

The results of the simulations with the body axes initially coincident with the inertial axes clearly indicate the coupling of pitch and surge which bring about the trajectories of Figure IV.1. This motion becomes even more clear in the velocity plots of Figure IV.2. A tendancy toward a negative pitch angle when dumping both trim tanks into the reservoir is also demonstrated.

The simulations involving an initial roll angle indicate the small amount of roll damping and static stability associated with this vehicle. They also indicate a slight side force roll coupling as is evidenced in the printout in Appendix C, section C - 2. The lack of stability also manifested itself by causing the program to terminate prematurely when using a time increment that proved successful for the zero roll case. Eventually an increment of one tenth that used without roll proved successful.



Ascent (feet)
0
200
400
600
800
1000
1200
Time (sec)
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
x_o
Ascent
Pitch
-100
-80
-60
-40
-20
0
20
-1.0
-.5
.5
1.0
x_o (feet)
Pitch (radians)

Figure IV.1

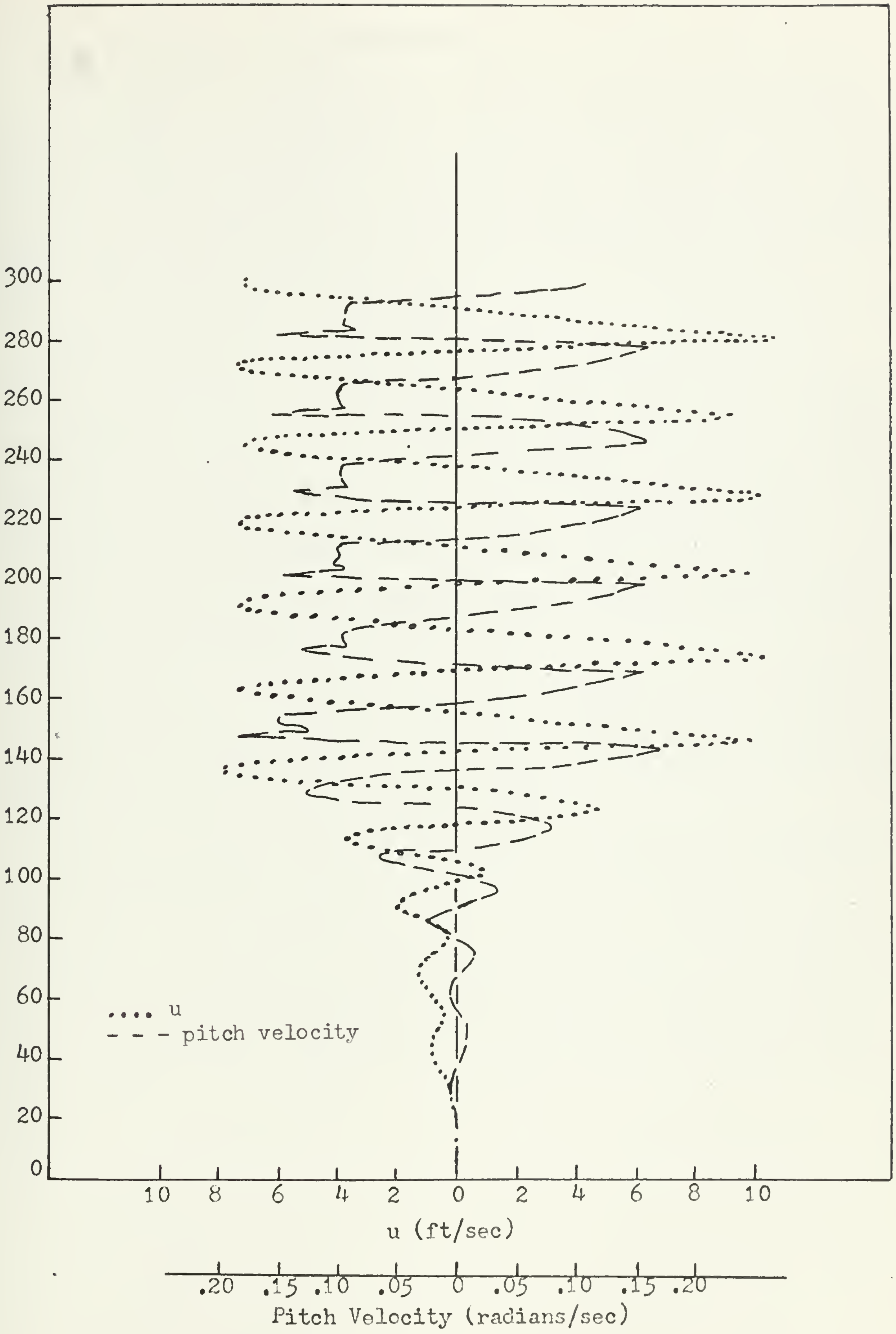

300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
.... u
- - - pitch velocity
10 8 6 4 2 0 2 4 6 8 10
u (ft/sec)
.20 .15 .10 .05 0 .05 .10 .15 .20
Pitch Velocity (radians/sec)

Figure IV.1

IV - 2 Conclusions and Recommendations

The computer simulations using the DSRV characteristics have demonstrated the worth of this program in determining the motions of a vehicle as it ascends under the influence of buoyancy alone. They have shown that a vehicle such as the DSRV is quite sensitive to roll without the stabilizing effect of a relatively large forward velocity.

The velocities achieved by the vehicle during ascent indicate that there is a predominant velocity component about which we could expand a Taylor series once the initial acceleration phase of the ascent has been passed. The most likely time for a shift to this sort of formulation is twenty seconds after deballasting has been completed. At that time the vehicle appears to have reached a terminal condition in which the surge and pitch vary between essentially constant limits.

The simulations have indicated that a vehicle with near perfect port and starboard symmetry requires no more than two dimensional equations of motion when there are no side forces present.

It is recommended that future studies be made using coefficients obtained from model tests conducted without propellers running. Also, in view of the slow ascent velocities, it may prove worthwhile to rewrite the equations to include the effects of an ascent propulsor which may prove necessary in order to get a more rapid ascent in other than emergency situations.

REFERENCES

1. Lamb, Sir Horace, "Hydrodynamics", Sixth Edition, Dover Publications, New York (1945).

2. Strumpf, Albert, "Equations of Motion of a Submerged Body with Varying Mass", Davidson Laboratory Report No. 771, May 1960.

3. Abkowitz, Martin A., "The Dynamical Stability of Submarines", A lecture course and notes, June 1949, (limited circulation).

4. Parissis, Gregory G., "The Effect of Hull Shape Non-Linearities on the Calculation of Heave and Pitch of a Ship", MIT, Department of Naval Arch. and Marine Engineering, Contract Report No. DSR 5054, June 1964.

5. Broxmeyer, C., Dogan, P. P., MacKennon, D., McCloskey, I. M., Meiry, J. L., Sklar, S. J., "Deep Submergence Rescue Vehicle Simulation and Ship Control Analysis", MIT Instrumentation Laboratory Report No. R - 570 - A, February 1967.

6. Bulletin No. 1 - 5, "Nomenclature for Treating the Motion of a Submerged Body Through a Fluid", SNAME, April 1952.

7. Abkowitz, M. A., "Lectures on Advanced Ship Hydrodynamics", Delivered in Fall 1968, at MIT, Cambridge, Massachusetts.

8. Gertler, Morton, Hagen Grant R., "Standard Equations of Motion for Submarine Simulation", Naval Ship Research and Development Center, Report No. 2510, June 1967.

9. Giddings, Alfred J., Louis, William L., "Overcoming Submarine Control-Surface Jams and Flooding Casualties", Naval Engineers Journal, Volume 78, No. 6, December 1966.

10. Abkowitz, M. A., "Lectures on Ship Hydrodynamics - Steering and Manoeuvrability", Hydro - and Aerodynamics Laboratory Report No. Hy - 5, May 1964. (This report contains essentially the same material as ref 3 but is not limited in circulation.)

11. McCraken, D. D., "A Guide to FORTRAN Programming, Wiley and Sons, 1961.

12. IBM Systems Reference Library, "IBM System/360 FORTRAN IV Language," Form C28 - 6515 - 7.

13. IBM Application Program "System 360 Scientific Subroutine Package", Version III, form H20 - 0205 - 3.

14. IBM Systems Reference Library, "IBM System/360 FORTRAN IV Library Subprograms", Form C28 - 6596 - 4.

15. Young, D. B., "Model Investigation of the Stability and Control Characteristics of the Contract Design for the Deep Submergence Rescue Vehicle (DSRV)", Naval Ship Research and Development Center, Report No. 3030, April 1969.

APPENDIX A

COMPUTER PROGRAM FOR ASCENT TRAJECTORIES

A - 1 General:

The computer program to calculate free ascent trajectories is written for the IBM 360 - 65 digital computer of the MIT Information Processing Center. The program is written in FORTRAN IV (see ref 11 and 12). The program makes use of the matrix manipulation subroutines contained in version III of the IBM "Scientific Subroutine Package" (ref 13) and the mathematical functions contained in the standard "Library Subroutines" (ref 14).

The system subroutines required are:

Library Subroutines;

SIN - computes the sine of an angle

COS - computes the cosine of an angle

TAN - computes the tangent of an angle

SQRT - computes the square root of a number

ABS - computes the absolute value of a number

Scientific Subroutines;

GMPRD - computes the product of two matrices

MINV - computes the inverse of a matrix

Extensive use is made of the NAMELIST feature of FORTRAN IV for input and output.

The program is divided into seven parts: the MAIN program and six SUBROUTINES.

A - 1.1 MAIN Program

The MAIN program acts as an executive reading in initial conditions, vehicle parameters and program control parameters, calling the various subroutines needed to solve the equations of motion and writing out the results of the computations.

The data read in is contained in five NAMELISTS, INCOND, FLUID, VLMITS, VEHICL and CONTRL, and one controlled format statement. The output is again in accordance with the NAMELISTS plus a single large array, POSIT, containing all the computed results for the entire test period.

Part of the output from MAIN is a set of punched cards which contain all the parameters from NAMELIST INCOND. This output can be used as input data for another run in order to continue the same trajectory if it is desired. A maximum of five hundred steps is allowed in one run.

A - 1.2 Subroutine COEFF

COEFF reads in the non-dimensional coefficients and immediately prints them for output. The subroutines then computes dimensionalizing factors, dimensionalizes the coefficients for use in the motion equations and prints the dimensionalized coefficients for output.

The coefficients are read in and printed using the NAMELIST COEFFS.

The dimensionless coefficients are replaced in storage by their dimensional form.

A - 1.3 Subroutine BALAST

BALAST computes the changes in weight, mass, center of gravity, and moments of inertia due to the dropping of ballast.

This subroutine is only called during the initial phase of the

trajectory when deballasting takes place.

BALAST calls subroutine AMATRX since the matrix generated in AMATRX varies only during the deballasting phase of the ascent.

A maximum of twenty locations for ballast weights is allowed.

There is no printed output from BALAST.

A - 1.4 Subroutine AMATRX

AMATRX computes the six by six matrix of acceleration term coefficients, AM, and then inverts the array for use in the solution of the equations of motion.

A - 1.5 Subroutine HYDRO

HYDRO computes the hydrodynamic forcing terms and the gravity forcing terms and then sums them, plus any effector forces, to get the total forcing terms for the equations of motion.

HYDRO uses the velocities and angles resulting from the previous steps in order to compute the hydrodynamic and gravity force components acting on the vehicle during the present step.

There is no printed output from HYDRO.

A - 1.6 Subroutine TRAJEC

TRAJEC computes the translational and rotational velocities of the vehicle in both body fixed and earth fixed axis systems. In order to do this, TRAJEC also computes the translational and angular velocity transformation matrices AINV and TINV.

If the pitch angle becomes ninety degrees the transformation matrix, AINV, will blow up (mathematically speaking). At this time, the program will print a message saying that this has occurred. At the same time, the computer system will issue a "IBM interrupt, Divide check" message

during computation of the two elements in ALW which involve division by the cosine of the pitch angle. At this point the system will take the standard corrective action of assigning the value of 10**69 to each of these elements.

A - 1.7 Subroutine: POSITN

POSITN computes the time ellapsed and the position of the vehicle relative to the earth fixed origin. The vehicle position includes both translation and rotation. POSITN also stores all the trajectory generation information in the array POSIT for the final output sequence.

There is no printed output from POSITN.

A - 2 Input-Output

The variables and constants needed as input for this computer program are read into the program by seven read statements. Table 1 lists all the input variables and the formats under which they are read.

A single computer run must be made to simulate each vehicle. If, however, a run terminates before the vehicle reaches the surface, the punched output from the program gives the input necessary to continue the trajectory on the next run.

The program output gives a time history of the simulation. This data is stored in an array during execution and printed at the end of the run by the main program. During program execution NAMELIST/INCOND/ is printed at the completion of each step. This is done to aid the user in locating the source of any premature program termination. Premature termination is generally caused by incorrect input data.

The dimensions of the storage array restricts the program to 500 time intervals, however, the program storage requirements are such that this dimension can safely be increased to 1000. This, coupled with the

ability to continue a trajectory from one run to the next, allows an unlimited number of intervals during a trajectory.

For sample output see Appendix C.

TABLE 1

INPUT TO ASCENT PROGRAM

Columns	Format	Symbol	Description
2 - 8		$INCOND	This namelist will take more than one card and includes the variables described in Table 2. The list begins with $INCOND and ends with $END.
2 - 7		$FLUID	This namelist will take one card and includes the variables described in Table 2.
2 - 8		$VIMITS	This namelist will take one card and includes the variables described in Table 2.
2 - 8		$VEHICL	This namelist will take one card and includes the variables described in Table 2.
2 - 8		$CONTRL	This namelist will take one card and includes the variables described in Table 2.
2 - 8		$COEFFS	This namelist will take more than one card and includes the variables listed in Tables 2 and 3.
1 - 10	F 10.0	XI	The position of the ballast weight relative to
11 - 20	F 10.0	YI	the origin of the body axis coordinates.
21 - 30	F 10.0	ZI	(feet).

Columns	Format	Symbol	Description
31 - 40	F 10.0	DMASS	The rate at which the particular ballast weight is removed (pounds per second).
41 - 45	I 5	IMAXI	The number of time steps during which a particular ballast weight is removed. There is one card of this type for each position from which ballast is removed.

A - 3 Description of Namelists

The following tables contain the NAMELISTS used by the program.

TABLE 2

NAMELISTS

Name List/INCOND/

PROGRAM VARIABLE	USUAL NOMENCLATURE	DEFINITION & UNITS
ISTEP		The step number
DT	Δt	The time interval used during deballasting (seconds)
TIME	t	The time elapsed since ascent commenced (seconds)
XE	x_E	The x component of the distance traveled relative to the inertial origin (feet)
YE	y_E	The y component of the distance traveled relative to the inertial origin (feet)
ZE	z_E	The z component of the distance traveled relative to the inertial origin (feet)
PHI	ϕ	The angle of roll (radians)
THETA	θ	The angle of pitch (radians)
PSI	ψ	The angle of yaw (radians)

PROGRAM VARIABLE	USUAL NOMENCLATURE	DEFINITION & UNITS
VEARTH	$\vec{\dot{x}}$	The vehicle vector of translational velocity in inertial coordinates (feet per second)
WEARTH	$\vec{\dot{\phi}}$	The vehicle vector of angular velocity in inertial coordinates (radians per second)
BVEL	$\vec{v}$	The vehicle vector of translational velocity in the Body axis system (feet per second)
BROT	$\vec{w}$	The vehicle vector of angular velocity in the Body axis system (radians per second)
WT	W	The vehicle weight (pounds)
XG	x_G	The x components of the CG vector (feet)
YG	y_G	The y component of the CG vector (feet)
ZG	z_G	The z component of the CG vector (feet)
B	B	The vehicle buoyant force (pounds)
XB	x_B	The x component of the CB vector (feet)
YB	y_B	The y component of the CB vector (feet)
ZB	z_B	The z component of the CB vector (feet)
IXX	I_{xx}	The mass moment of inertia about the x axis (slugs)
IYY	I_{yy}	The mass moment of inertia about the y axis (slugs)
IZZ	I_{zz}	The mass moment of inertia about the z axis (slugs)

PROGRAM VARIABLE	EQUIVALENT NOMENCLATURE	DEFINITION (cont'd)
IXZ	I_{xz}	The product of inertia about the y-axis ([illegible])
DT,	Δt	The time interval at which deballasting is computed (seconds)
		Name List/FLUID/
GAMMA	γ	The fluid specific weight (pounds per cubic foot)
RO	ρ	The fluid density (slugs per cubic foot)
ZZERO	Z_o	The depth of the vehicle at the start of the ascent (feet)
		Name List/[illegible]/
[illegible]		Maximum allowed ascent time (seconds)
JMAX		The number of locations from which ballast is released
JSTEPS		The number of steps required to complete deballasting
		Name List/[illegible]/
VMASS	m	Total mass of the vehicle (slugs)
LENGTH	l	Vehicle length used for non-dimensionalizing purposes (feet)
VOLUME	$\forall$	Displaced volume of submersible (cubic feet)

Name List/CO[illegible]/

PROGRAM VARIABLE	USUAL NOMENCLATURE	DEFINITION & UNITS
XEFF	X_{EFF}	The X component of the effector forces (pounds)
YEFF	Y_{EFF}	The Y component of the effector forces (pounds)
ZEFF	Z_{EFF}	The Z component of the effector forces (pounds)
KEFF	K_{EFF}	The K component of the effector forces (pounds)
MEFF	M_{EFF}	The M component of the effector forces (pounds)
NEFF	N_{EFF}	The N component of the effector forces (pounds)
		Name List/COEFFS/
X	X_{ij}	Longitudinal force coefficients for a vehicle moving ahead
XA	XA_{ij}	Longitudinal force coefficients for a vehicle moving astern
Y	Y_{ij}	Lateral force coefficients for a vehicle moving ahead
YA	YA_{ij}	Lateral force coefficients for a vehicle moving astern
Z	Z_{ij}	Normal force coefficients for a vehicle moving ahead
ZA	ZA_{ij}	Normal force coefficients for a vehicle moving astern

PROGRAM VARIABLE	USUAL NOMENCLATURE	DEFINITIONS & UNITS
K	K_{ij}	Roll Moment force coefficients for a vehicle moving ahead
KA	KA_{ij}	Roll Moment force coefficients for a vehicle moving astern
M	M_{ij}	Pitch Moment force coefficients for a vehicle moving ahead
MA	MA_{ij}	Pitch Moment force coefficients for a vehicle moving astern
N	N_{ij}	Yaw Moment force coefficients for a vehicle moving ahead
NA	NA_{ij}	Yaw Moment force coefficients for a vehicle moving astern

The subscripts i, j refer to the possible combinations of the body velocities and accelerations as described in Table 3.

TABLE 3

COEFFICIENTS

PROGRAM SUBSCRIPT	STANDARD (NSRDC) SUBSCRIPT NOMENCLATURE X, XA	Y, YA	Z, ZA	K, KA	M, MA	N, NA
1	uu	v|v|	u or *	v|v|	u	v|v|
2	vv	v	vv	v	vv	
3	ww		w|w|	vw	w|w|	vw
4		vw	w	uu or *	w	v
5		uu or *	w		vw	uu or *
6			ww		w	
7	$\dot{u}$	$\dot{v}$	$\dot{u}$	$\dot{v}$	$\dot{u}$	$\dot{v}$
8	$\dot{w}$	p	$\dot{w}$	p	$\dot{w}$	vr
9	uq	r	vp	r	vp	wp
10	vr	vq	vr	vq	vr	vq
11	wq	wp	q	wp	q	p
12		wr	w|q|	wr	|w|q	r
13						|v|r
14	qq	$\dot{p}$	$\dot{q}$	$\dot{p}$	$\dot{q}$	$\dot{p}$
15	rr	$\dot{r}$	pp	$\dot{r}$	pp	$\dot{r}$
16	rp	pq	qq	p|p|	q|q|	|r|r
17	$\dot{q}$	qr	rr	pq	rr	pq
18			rp	qr	rp	qr

A - 4 Program Listings

```
C     ASCENT.....A PROGRAM TO COMPUTE THE ASCENT TRAJECTORY FOR A
C                DEEP SUBMERSIBLE BY [illegible]. .TUFTS .
C
C      THIS PROGRAM COMPUTES A STEPWISE SOLUTION TO A SET OF SECOND
C      ORDER EQUATIONS OF MOTION IN SIX DEGREES OF FREEDOM WITH
C      VARIABLE MASS AND CENTER OF GRAVITY.
C
C     MAIN ROUTINE
C
      REAL K,M,N,KEFF,MEFF,NEFF,IXX,IYY,IZZ,IXZ,KA,MA,NA
      DIMENSION POSIT(51,500),AM(6,6),X(18),Y(18),Z(18),K(18),M(18),N(18
     2),DDT(6),DDTP(6),VEARTH(3),REARTH(3),PVEL(3),PROT(3),F(18),C(18),
     3XA(18),YA(18),ZA(18),KA(18),MA(18),NA(18),XI(20),YI(20),ZI(20),
     4DMASS(20),IMAXI(20)
      COMMON POSIT,AM,X,Y,Z,K,M,N,DDT,DDTP,VEARTH,REARTH,PVEL,PROT,[illegible],
     2GAMMA,IXX,IYY,IZZ,IXZ,PHI,THETA,PSI,RO,U,V,W,P,Q,R,VMASS,VLENTH,
     3VOLUME,XEFF,YEFF,ZEFF,KEFF,MEFF,NEFF,XG,YG,ZG,DT,TIME,
     4TTOTAL,ZZERO,XE,YE,ZE,XB,YB,ZB,XA,YA,ZA,KA,MA,NA,XI,YI,ZI,DMASS,
     5XBB,YBB,ZBB,CONST,ISTEP,IMAX,IMAXI
      NAMELIST/INCOND/ISTEP,DT,TIME,XE,YE,ZE,PHI,THETA,PSI,VEARTH,REARTH
     2,PVEL,PROT,DT,XG,YG,ZG,B,XB,YB,ZB,IXX,IYY,IZZ,IXZ,DTO/FLUID/GAMMA,
     3RO,ZZERO/WEIGHTS/TTOTAL,IMAX,ISTEP/VEHICL/VMASS,VLENTH,VOLUME/CONT
     4RL/XEFF,YEFF,ZEFF,KEFF,MEFF,NEFF
      DO 100 I=1,51
      DO 100 J=1,[illegible]
  100 POSIT(I,J) = [illegible]
      READ(5,INCOND)
      READ(5,FLUID)
      READ(5,WEIGHTS)
      READ(5,VEHICL)
      READ(5,CONTRL)
      WRITE(6,[illegible])
      WRITE(6,FLUID)
      WRITE(6,WEIGHTS)
      WRITE(6,VEHICL)
      WRITE(6,CONTRL)
      WRITE(6,INCOND)
```

```
      ISTART = ISTEP
      POSIT(3,ISTEP) = XE
      POSIT(4,ISTEP) = YE
      POSIT(5,ISTEP) = ZE
      POSIT(6,ISTEP) = PHI
      POSIT(7,ISTEP) = THETA
      POSIT(8,ISTEP) = PSI
      U = BVEL(1)
      V = BVEL(2)
      W = BVEL(3)
      P = BROT(1)
      Q = BROT(2)
      R = BROT(3)
      CONST =32.17405
      B = GAMMA *VOLUME
      CALL COEFF
      READ(5,500) (XI(I),YI(I),ZI(I),DMASS(I),IMAXI(I),I=1,IMAX)
      DO 2 I=1,IMAX
    2 DMASS(I) = DMASS(I) * DT
      YBB = YB * B
      ZBB = ZB * B
      XBB = XB * B
    1 ISTEP = ISTEP + 1
      IF( ISTEP .LE. ISTEPB ) CALL BALAST
      IF( ISTEP .GT. ISTEPB ) DT = DTB
      CALL HYDRO
      CALL TRAJEC
      CALL POSITN
      XE = POSIT(3,ISTEP)
      YE = POSIT(4,ISTEP)
      ZE = POSIT(5,ISTEP)
      WRITE(6,INCOND)
      IF( TIME .GE. TTOTAL ) GO TO 9999
      IF( POSIT(5,ISTEP) .GE. ZZERO ) GO TO 9999
      GO TO 1
 9999 WRITE(7,INCOND)
      ISTOP = ISTEP
```

```
66   ISTEP = ISTART + 4[illegible]
     IF( ISTEP .GT. ISTOP ) ISTEP = ISTOP
     WRITE(6,5[illegible])
     WRITE(6,5[illegible])
     WRITE(6,6[illegible]5) (J,(POSIT(I,J),I=1,[illegible]),J=ISTART,ISTEP)
     WRITE(6,599)
     WRITE(6,601)
     WRITE(6,606) (J, POSIT(2,J),(POSIT(I,J),I=9,14),J=ISTART,ISTEP)
     WRITE(6,599)
     WRITE(6,602)
     WRITE(6,606) (J, POSIT(2,J),(POSIT(I,J),I=15,20),J=ISTART,ISTEP)
     WRITE(6,599)
     WRITE(6,603)
     WRITE(6,606) (J, POSIT(2,J),(POSIT(I,J),I=21,26),J=ISTART,ISTEP)
     WRITE(6,599)
     WRITE(6,604)
     WRITE(6,607) (J, POSIT(2,J),(POSIT(I,J),I=27,33),J=ISTART,ISTEP)
     ISTART = ISTEP + 1
     IF( ISTEP .LT. ISTOP )GO TO 66
598  FORMAT(1H1 .[illegible],T5)
599  FORMAT(1H0,/////)
600  FORMAT     (4X('STEP     NT          TIME          X          Y          Z
   C              NO         (HOURS)        (FT)'//)
601  FORMAT     (6X('STEP         TIME         J          X          Z
   C                 ',/28X,6('[illegible]I1',5X)//)
602  FORMAT     (6X('STEP         TIME         J          V          W
   C                 ',/27X,6('[illegible]DOT',7X)//)
603  FORMAT     (6X('STEP         TIME        U DOT       V DOT       W DOT       P
   C DOT           Q DOT          R DOT'//)
604  FORMAT     (6X('STEP         TIME        [illegible]          XG          YG          ZG
   C        YANCY'//)
605  FORMAT     (2X,I4,2X,F[illegible].2,2X,F[illegible].2,2X,F9.1,2X,F9.1,2X,F9.1,2X,F9.2,2X
   C,F9.2,2X,F9.2)
606  FORMAT     (2X,I4,2X,F7.2,2X,F[illegible].3,2X,F[illegible].3,2X,F9.3,2X,F9.3,2X,F9.3,2X
   C,F9.2)
607  FORMAT     (2X,I4,2X,F7.2,2X,F[illegible].1,2X,F7.3,2X,F7.3,2X,F7.3,2X,F9.1)
     RETURN
     END
```

```
      SUBROUTINE COEFF
C
      REAL K,M,N,KEFF,MEFF,NEFF,IXX,IYY,IZZ,IXZ,KA,MA,NA
      DIMENSION POSIT(31,500),A(6,6),X(18),Y(18),Z(18),K(18),M(18),N(18
     2),DOT(6),DOTP(6),VEARTH(3),WEARTH(3),WVEL(3),WROT(3),F(13),G(13),
     3XA(18),YA(18),ZA(18),KA(18),MA(18),NA(18),XI(20),YI(20),ZI(20),
     4MASS(20)
      COMMON POSIT,AM,X,Y,Z,K,M,N,DOT,DOTP,VEARTH,WEARTH,WVEL,WROT,F,DT,
     2GAMMA,IXX,IYY,IZZ,IXZ,PHI,THETA,PSI,UO,U,V,W,P,Q,R,VMASS,VLENTH,
     3VOLUME,XEFF,YEFF,ZEFF,KEFF,MEFF,NEFF,XG,YG,ZG,NT,TIME,
     4TTOTAL,ZZERO,XF,YF,ZF,XP,YP,ZP,XA,YA,ZA,KA,MA,NA,XI,YI,ZI,MASS,
     5XBB,YBB,ZBB,CONST,ISTEP,IMAX
      NAMELIST/COEFFS/X,XA,Y,YA,Z,ZA,K,KA,M,MA,N,NA
      READ(5,COEFFS)
      WRITE(6,COEFFS)
      PL2 = RHO*VLENTH*VLENTH/2.0
      PL3 = PL2*VLENTH
      PL4 = PL3*VLENTH
      PL5 = PL4*VLENTH
      DO 10 I=1,6
      XA(I) = PL2 * XA(I)
      YA(I) = PL2 * YA(I)
      ZA(I) = PL2 * ZA(I)
      KA(I) = PL3 * KA(I)
      MA(I) = PL3 * MA(I)
      NA(I) = PL3 * NA(I)
      X(I) = PL2 * X(I)
      Y(I) = PL2 * Y(I)
      Z(I) = PL2 * Z(I)
      K(I) = PL3 * K(I)
      M(I) = PL3 * M(I)
   10 N(I) = PL3 * N(I)
      DO 20 I=1,7
      XA(I+6) = PL3 * XA(I+6)
      YA(I+6) = PL3 * YA(I+6)
      ZA(I+6) = PL3 * ZA(I+6)
      KA(I+6) = PL4 * KA(I+6)
```

```
      MA(I+6 ) = PL4 * MA(I+6 )
      NA(I+6 ) = PL4 * NA(I+6 )
      X(I+6 ) = PL3 * X(I+6 )
      Y(I+6 ) = PL3 * Y(I+6 )
      Z(I+6 ) = PL3 * Z(I+6 )
      K(I+6 ) = PL4 * K(I+6 )
      M(I+6 ) = PL4 * M(I+6 )
   20 N(I+6 ) = PL4 * N(I+6 )
      DO 30 I=1,7
      XA(I+13) = PL4 * XA(I+13)
      YA(I+13) = PL4 * YA(I+13)
      ZA(I+13) = PL4 * ZA(I+13)
      KA(I+13) = PL4 * KA(I+13)
      MA(I+13) = PL4 * MA(I+13)
      NA(I+13) = PL4 * NA(I+13)
      X(I+13) = PL4 * X(I+13)
      Y(I+13) = PL4 * Y(I+13)
      Z(I+13) = PL5 * Z(I+13)
      K(I+13) = PL5 * K(I+13)
      M(I+13) = PL5 * M(I+13)
   30 N(I+13) = PL5 * N(I+13)
      WRITE(3,[illegible]S)
      RETURN
      END
```

```
      SUBROUTINE BALAST
C
      REAL M,N,R,KTHE,MEFF,NEFF,IXX,IYY,IZZ,IXZ,KA,MA,NA
      DIMENSION POSIT(21,500),AM(6,6),X(18),Y(18),Z(18),K(18),M(18),N(1
     2),DOT(6),DDTP(6),VEARTH(3),VEARTH(3),BVEL(3),DROT(3),F(13),C(13),
     3XA(18),YA(18),ZA(18),KA(18),MA(18),NA(18),XI(20),YI(20),ZI(20),
     4DMASS(20),IMAXI(20)
      COMMON POSIT,AM,X,Y,Z,K,M,N,DOT,DDTP,VEARTH,VEARTH,BVEL,DROT,R,DT,
     2AM,MA,IXX,IYY,IZZ,IXZ,PHI,THETA,PSI,U,V,W,P,Q,R,VMASS,VLENTH,
     3MEL,XEFF,YEFF,ZEFF,KTHE,MEFF,NEFF,XG,YG,ZG,WT,TIME,
     4TTOTAL,ZZERO,KZ,YZ,ZZ,XB,YB,ZB,XA,YA,ZA,KA,MA,NA,XI,YI,ZI,DMASS,
     5YB3,YB3,ZB3,CONST,ISTEP,IMAX,IMAXI
   10 IF(ISTEP-1 .GT. IMAXI(IMAX) ) IMAX = IMAX - 1
      IF(IMAX .LE. 0 ) RETURN
      IF( ISTEP-1 .GT. IMAXI(IMAX)) GO TO 30
      SUMX = 0.0
      SUMY = 0.0
      SUMZ = 0.0
      SUMXX = 0.0
      SUMYY = 0.0
      SUMZZ = 0.0
      SUMXZ = 0.0
      SUMM = 0.0
      DO 20 I=1,IMAX
      SUM1 = DMASS(I) * XI(I)
      SUM2 = DMASS(I) * YI(I)
      SUM3 = DMASS(I) * ZI(I)
      SUMM = DMASS(I) + SUMM
      SUMX = SUMX + SUM1
      SUMY = SUMY + SUM2
      SUMZ = SUMZ + SUM3
      SUMXX = SUMXX + SUM1 * XI(I)
      SUMYY = SUMYY + SUM2 * YI(I)
      SUMZZ = SUMZZ + SUM3 * ZI(I)
   20 SUMXZ = SUMXZ + SUM1 * ZI(I)
```

```
XWT = XG * WT
YWT = YG * WT
ZWT = ZG * WT
WT = WT -SUMW
VMASS = WT / CONST
XG = (XWT - SUMX)/WT
YG = (YWT - SUMY)/WT
ZG = (ZWT - SUMZ)/WT
IXX = IXX - ( SUMYY + SUMZZ )/ CONST
IYY = IYY - ( SUMZZ + SUMXX )/ CONST
IZZ = IZZ - ( SUMXX + SUMYY )/ CONST
IXZ = IXZ - SUMXZ / CONST
CALL MATRX
RETURN
END
```

```
      SUBROUTINE AMATRX
C
      REAL K,M,N,KEFF,MEFF,NEFF,IXX,IYY,IZZ,IXZ,K1,MA,NA
      DIMENSION L1(6),L2(6)
      DIMENSION POSIT(31,500),AM(6,6),X(13),Y(18),Z(18),K(18),M(18),N(18
     2),DOT(6),DDTP(6),VEARTH(3),PEARTH(3),PVEL(3),PDOT(3),F(13),C(13),
     3XA(13),YA(13),ZA(13),KA(13),MA(13),NA(13),XI(20),YI(20),ZI(20),
     4DMASS(20)
      COMMON POSIT,AM,X,Y,Z,K,M,N,DOT,DDTP,VEARTH,PEARTH,PVEL,PDOT,F,C,ET,
     2GAMMA,IXX,IYY,IZZ,IXZ,PHI,THETA,PSI,U,V,W,P,Q,R,VMASS,VLENGTH,
     3VOLUME,XEFF,YEFF,ZEFF,KEFF,MEFF,NEFF,XG,YG,ZG,DT,TIME,
     4TOTAL,ZERO,XB,YB,ZB,XA,YA,ZA,KA,MA,NA,XI,YI,ZI,DMASS,
     5XBB,YBB,ZBB,CONST,ISTEP,IMAX
C     SET UP ARRAY AM
      AM(1,1) = VMASS - X(7)
      AM(2,1) = 0.0
      AM(3,1) = - Z(7)
      AM(4,1) = 0.0
      AM(5,1) = VMASS * ZG - M(7)
      AM(6,1) = - VMASS * YG
      AM(1,2) = 0.0
      AM(2,2) = VMASS - Y(7)
      AM(3,2) = 0.0
      AM(4,2) = - VMASS * ZG - K(7)
      AM(5,2) = 0.0
      AM(6,2) = VMASS * XG - N(7)
      AM(1,3) = -X([illegible])
      AM(2,3) = 0.0
      AM(3,3) = VMASS - Z([illegible])
      AM(4,3) = VMASS * YG
      AM(5,3) = - VMASS * XG - M([illegible])
      AM(6,3) = 0.0
      AM(1,4) = 0.0
      AM(2,4) = - VMASS * ZG - Y(14)
      AM(3,4) = - VMASS * YG
      AM(4,4) = IXX - K(14)
      AM(5,4) = 0.0
```

```
      AM(6.4) = IXZ - N(14)
      AM(1,5) = - X(17)
      AM(2,5) = 0.0
      AM(3,5) = - VMASS * XG - Z(14)
      AM(4,5) = 0.0
      AM(5,5) = IYY - M(14)
      AM(6,5) = 0.0
      AM(1.6) = - VMASS * YG
      AM(2,6) = - VMASS * XG - Y(15)
      AM(3,6) = 0.0
      AM(4,6) = IXZ - K(15)
      AM(5.6) = 0.0
      AM(6,6) = IZZ - N(15)
C     INVERT AM
      CALL MINV(AM,6.D,LL,LN)
      RETURN
      END
```

```
      SUBROUTINE HYDRO
C
      REAL K,M,N,KEFF,MEFF,NEFF,IXX,IYY,IZZ,IXZ,KA,MA,NA
      REAL KHYD,MHYD,NHYD,KGRAV,MGRAV,NGRAV
      DIMENSION POSIT(31,500),AM(6,6),X(18),Y(18),Z(18),K(18),M(18),N(18
     2),UDOT(6),DDTP(6),VEARTH(3),WEARTH(3),RVEL(3),RROT(3),H(13),C(13),
     3XA(18),YA(18),ZA(18),KA(18),MA(18),NA(18),XI(20),YI(20),ZI(20),
     4XMASS(20)
      COMMON POSIT,AM,X,Y,Z,K,M,N,UDOT,DDTP,VEARTH,WEARTH,RVEL,RROT,H,C,T,
     2GAMMA,IXX,IYY,IZZ,IXZ,PHI,THETA,PSI,UO,U,V,W,P,Q,R,VMASS,VLENTH,
     3VOLUME,XEFF,YEFF,ZEFF,KEFF,MEFF,NEFF,XG,YG,ZG,DT,TIME,
     4TTOTAL,ZZERO,XE,YE,ZE,XT,YT,ZT,XA,YA,ZA,KA,MA,NA,XI,YI,ZI,XMASS,
     5XPP,YPP,ZPP,CONST,ISTEP,IWAY
      UU = U * U
      VV = V * V
      WW = W * W
      PP=P*P
      QQ=Q*Q
      RR=R*R
      UV = U*V
      UW=U*W
      UP = U*P
      UQ=U*Q
      UR=U*R
      VW=V*W
      VP=V*P
      VQ=V*Q
      VR=V*R
      WP=W*P
      WQ=W*Q
      WR=W*R
      PQ=P*Q
      PR=P*R
      QR=Q*R
      AU=ABS(U)
      AV = ABS(V)
      AW=ABS(W)
```

```
 AVW=ABS(SQRT(VV+WW))
 UAU=U*AU
 PAP=P*ABS(P)
 QAQ=Q*ABS(Q)
 RAR=R*ABS(R)
 UAV=U*AV
 VAV = V*AV
 VAW=V*AW
 VAU=V*AU
 WAU=W*AU
 PAU=P*AU
 QAU=Q*AU
 QAV = Q*AV
 RAU=R*AU
 WAV=W*ABS(V)
 VAVW=V*AVW
 WAVW=W*AVW
 SIGN = +1.0
 IF( Q .LT. 0.0 ) SIGN = -1.0
 IF( U .LT. 0.000) GO TO 5
 XHY) = VMASS * ( VR - WQ + XG * ( QQ + RR ) - YG * PQ - ZG * RP )+
2X(1) * UU + X(2) * VV + X(3) * [illegible] + [illegible] X(9) * [illegible] + X(12)*
3VR + X(13) * [illegible] + X(14) * UQ + X(15) * PR + X(16) * RP
 YHY) = VMASS * ( UR - WP + YG * ( RR + PP ) - ZG * QR - XG * PQ )+
2 Y(1) * VAV + Y(2) * UV + Y(3) * UR + Y(4) * [illegible] + Y(5) * UP +
3Y(8) * UP + Y(9) * UR + Y(10) * VQ + Y(11) * UP + Y(12) * QR +
4 Y(13) * UR + Y(16) * PQ + Y(17) * QR + Y(18) * PAP
 ZHY) = VMASS * ( UQ - VP + ZG * ( PP + QQ ) - XG * RP - YG * RQ )+
2 Z(1) * UU + Z(2) * VV + Z(3) * [illegible] + Z(4) * UQ + Z(5) * UAV +
3 Z(6) * ABS(UAV) + Z(7) * VP + Z(10) * VR + Z(11) * UW + Z(12) *
4 AVW * ABS( Q ) *SIGN [illegible] + Z(15) * PP + Z(16) * QQ + Z(17) * VP
5 + Z(18) * RR
 KHY) = - IXZ * PQ + ( IYY - IZZ ) * QR -
2 VMASS * ( ZG * ( WP - UR ) + YG * ( VP - UQ )) + K(1) * VAV +
3 K(2) * UV + K(3) * VW + K(9) * UP + K(4) *UR + K(10) * VQ +
4 K(11) * WP + K(12) * QR + K(16) * PAP + K(17) * PQ + K(18) * QR
5 + K(4) * UU
```

```
 MHY) = - IXZ * ( RR - PP ) + ( IZZ - IXX ) * RP -
2 VMASS * ( YG * ( UQ - VP ) + ZG * ( WQ - VR )) + M(1) * UU +
3 M(2) * VV + M(3) * WAVW + M(4) * UW + M(5) * ABS ( WAVW ) +
4 M(6) * UAW + M(9) * VP + M(10) * VR + M(11) * UQ + M(12) * AVW *
5 Q + M(15) * PP + M(16) * QAW + M(17) * RR + M(18) * RP
 NHY) = -IXZ * QR + ( IXX - IYY ) * PQ -
2 VMASS * ( YG * ( VR - WQ ) + XG * ( UQ - WP )) + N(1) * VAVW +
3 N(2) * UV + N(3) * VW + N(8) * WR + N(9) * WP + N(10) * VQ +
4 N(11) * UP + N(12) * UR + N(13) * AVW * R + N(16) * PAR +
5 N(17) * PQ + N(18) * QR +N(4) * UV + N(5) * UU
 GO TO 10
5 XFYD = VMASS * ( WQ - VR + XG * ( QQ + RR ) - YG * PQ - ZG * RP )+
2XA(1) * UU +XA(2) * VV +XA(3) * W [illegible] XA(9) * UQ +XA(10)*
3VR +XA(11) * UQ +XA(14) * [illegible] +XA(15) * RR +XA(16) * RP
 YFYD = VMASS * ( WP - UR + YG * ( RR + PP ) - ZG * QR - XG * PQ )+
2YA(1) * VAVW +YA(2) * UV +YA(3) * UV +YA(4) * VW +YA(5) * UU +
3YA(6)* UP +YA(9) * UR +YA(10) * VP +YA(11) * WP +YA(12) * QR +
4YA(13) * UP +YA(16) * PQ +YA(17) * QR +YA(18) * PAP
 ZFYD = VMASS * ( UQ - VP + ZG * ( PP + QQ ) - XG * RP - YG * QR )+
2ZA(1) * UU +ZA(2) * VV +ZA(3) * VAVW +ZA(4) * UW +ZA(5) * UAW +
3ZA(6) * ABS(WAVW) +ZA(9) * VP +ZA(10) * VR +ZA(11) * UQ +ZA(12)
4 * AVW * ABS( [illegible] ) * SIGN [illegible] +ZA(15) * PP +ZA(16) * QQ +ZA(17) * RR
5 +ZA(18) * RP
 KFYD = - IXZ * PQ + ( IYY - IZZ ) * QR -
2 VMASS * ( ZG * ( [illegible] - [illegible] ) + YG * ( VP - UQ )) +KA(1) * VAVW +
3KA(2) * UV +KA(3) * VW +KA(8) * WP +KA(9) * UR +KA(10) * VQ +
4KA(11) * WP +KA(12) * [illegible] +KA(16) * PAP +KA(17) * PQ +KA(18) * QR
5 +KA(4) * UU
 MFYD = - IXZ * ( RR - PP ) + ( IZZ - IXX ) * RP -
2 VMASS * ( XG * ( UQ - VP ) + ZG * ( WQ - VR )) +MA(1) * UU +
3MA(2) * VV +MA(3) * WAVW +MA(4) * UW +MA(5) * ABS ( WAVW ) +
4MA(6) * UAW +MA(9) * VP +MA(10) * VR +MA(11) * UQ +MA(12) * AVW *
5 Q +MA(15) * PP +MA(16) * QAW +MA(17) * RR +MA(18) * RP
 NFYD = -IXZ * QR + ( IXY - IYY ) * PQ -
2 VMASS * ( YG * ( VR - WQ ) + XG * ( UQ - WP )) +NA(1) * VAVW +
3 NA(2) * UV +NA(3) * VW +NA(8) * WR +NA(9) * WP +NA(10) * VQ +
4NA(11) * UP +NA(12) * UR +NA(13) * AVW * R +NA(16) * PAR +
```

```
     5NA(17) * P2 +NA(18) * Q2 +NA(4)* UV +NA(5) * UU
  10 S = SIN(THETA)
      CT = COS(THETA)
      CS = CT * SIN(PHI)
      CC = CT * COS(PHI)
      WB = WT - B
      XWB = XG * WT - XBB
      YWB = YG * WT - YBB
      ZWB = ZG * WT - ZBB
      XGRAV = - WB * S
      YGRAV = WB * CS
      ZGRAV = WB * CC
      KGRAV = YWB * CC - ZWB * CS
      MGRAV = - XWB * CC - ZWB * S
      NGRAV = XWB * CS + YWB * S
      DDTP(1) = XHYD + XGRAV + XEFF
      DDTP(2) = YHYD + YGRAV + YEFF
      DDTP(3) = ZHYD + ZGRAV + ZEFF
      DDTP(4) = KHYD + KGRAV + KEFF
      DDTP(5) = MHYD + MGRAV + MEFF
      DDTP(6) = NHYD + NGRAV + NEFF
      RETURN
      END
```

```
      SUBROUTINE TRAJEC
C
      REAL K,M,N,KEFF,MEFF,NEFF,IXX,IYY,IZZ,IXZ,KA,MA,NA
      DIMENSION AINV(3,3),TINV(3,3)
      DIMENSION POSIT(31,500),AH(6,6),X(18),Y(18),Z(18),K(18),M(18),N(18
     2),DDT(6),DDTP(6),VEARTH(3),XEARTH(3),BVEL(3),BROT(3),F(18),C(18),
     3XA(18),YA(18),ZA(18),KA(18),MA(18),NA(18),XI(20),YI(20),ZI(20),
     4DMASS(20)
      COMMON POSIT,AH,X,Y,Z,K,M,N,DDT,DDTP,VEARTH,XEARTH,BVEL,BROT,G,DT,
     2GAMMA,IXX,IYY,IZZ,IXZ,PHI,THETA,PSI,RO,U,V,W,P,Q,R,VMASS,VLENTH,
     3VOLUME,XEFF,YEFF,ZEFF,KEFF,MEFF,NEFF,XG,YG,ZG,IT,TIME,
     4TTOTAL,XCLPR,XE,YE,ZE,XP,YP,ZP,XA,YA,ZA,KA,MA,NA,XI,YI,ZI,DMASS,
     5XBP,YBP,ZBP,CONST,ISTEP,IMAX
C     DETERMINE ACCELERATIONS USING INVERSE OF ACCELERATION MATRIX
      CALL GMPRD(AH,DDTP,DDT,6,6,1)
C     DETERMINE BODY AXIS VELOCITIES
      U = U + DDT(1) * DT
      V = V + DDT(2) * DT
      W = W + DDT(3) * DT
      P = P + DDT(4) * DT
      Q = Q + DDT(5) * DT
      R = R + DDT(6) * DT
      BVEL(1) = U
      BVEL(2) = V
      BVEL(3) = W
      BROT(1) = P
      BROT(2) = Q
      BROT(3) = R
C     DETERMINE VELOCITIES RELATIVE TO EARTH FIXED AXES
C     TRANSFORMATION MATRIX GENERATION
      SP = SIN(PHI)
      CP = COS(PHI)
      ST = SIN(THETA)
      CT = COS(THETA)
      TT = TAN(THETA)
      SS = SIN(PSI)
      CS = COS(PSI)
```

```
      IF( ABS(CT) .LT. 0.00001) WRITE(6,600) ISTEP
  600 FORMAT(//10X'PITCH ANGLE IS FOUND TO 90 DEGREES AT STEP ',I5//)
      AINV(1,1) = 1.0
      AINV(2,1) = 0.0
      AINV(3,1) = 0.0
      AINV(1,2) = TT * SP
      AINV(2,2) = CP
      AINV(3,2) = SP/CT
      AINV(1,3) = TT*CP
      AINV(2,3) = SP
      AINV(3,3) = CP/CT
      TINV(1,1) = CT*CS
      TINV(2,1) = CT*SS
      TINV(3,1) = - ST
      TINV(1,2) = - CP*SS + ST*SP*CS
      TINV(2,2) = CP*CS + ST*SP*SS
      TINV(3,2) = CT*SP
      TINV(1,3) = SP*SS + ST*CP*CS
      TINV(2,3) = - SP*CS + ST*CP*SS
      TINV(3,3) = CT*CP
      CALL GMPRD(TINV,[illegible]VEL,V[illegible]TH,3,3,1)
      CALL GMPRD(AINV,[illegible],[illegible]TH,3,3,1)
      RETURN
      END
```

```
      SUBROUTINE POSIT
C
      REAL K,M,N,KEFF, EFF,MEFF,IXX,IYY,IZZ,IXZ,KA,MA,NA
      DIMENSION POSIT(31,500),AM(6,6),X(18),Y(18),Z(18),K(18),M(18),N(1
     2),DOT(6),DOTP(6),VEARTH(3),WEARTH(3),BVEL(3),BROT(3),A(13),C(13),
     3XA(18),YA(18),ZA(18),KA(18),MA(18),NA(18),XI(20),YI(20),ZI(20),
     4PMASS(20)
      COMMON POSIT,AM,X,Y,Z,K,M,N,DOT,DOTP,VEARTH,WEARTH,BVEL,BROT,B,DI,
     2GAMMA,IXX,IYY,IZZ,IXZ,PHI,THETA,PSI,RHO,U,V,W,P,Q,R,VMASS,VLENGTH,
     3VOLUME,XEFF,YEFF,ZEFF,KEFF,MEFF,NEFF,XG,YG,ZG,DT,TIME,
     4TTOTAL,ZZERO,XE,YE,ZE,XB,YB,ZB,XA,YA,ZA,KA,MA,NA,XI,YI,ZI,PMASS,
     5X33,Y33,Z33,COMSI,ISTEP,IMAX
      TIME = TIME + DT
      POSIT(1,ISTEP) = DT
      POSIT(2,ISTEP) = TIME
      DO 90 I=1,3
      POSIT(I+2,ISTEP) = POSIT(I+2,ISTEP-1) +
     C 0.5 * ( VEARTH(I) + POSIT(I+8,ISTEP-1)) * DT
   90 POSIT(I+5,ISTEP) = POSIT(I+5,ISTEP-1) +
     C 0.5 * ( WEARTH(I) + POSIT(I+11,ISTEP-1)) * DT
      ENTRY POSI[illegible]
      DO 100 I=1,3
       POSIT(I+8,ISTEP) = VEARTH(I)
       POSIT(I+11,ISTEP) = WEARTH(I)
       POSIT(I+14,ISTEP) = BVEL(I)
       POSIT(I+17,ISTEP) = BROT(I)
       POSIT(I+20,ISTEP) = DOT(I)
  100  POSIT(I+23,ISTEP) = DOT(I+3)
       POSIT(27,ISTEP) = U
       POSIT(28,ISTEP) = V
       POSIT(29,ISTEP) = W
       POSIT(30,ISTEP) = [illegible]
       POSIT(31,ISTEP) = [illegible]
       PHI   = POSIT(6,ISTEP)
       THETA = POSIT(7,ISTEP)
       PSI   = POSIT(8,ISTEP)
       RETURN
       END
```

APPENDIX B

TEST VEHICLE GEOMETRIC AND CONTROL CHARACTERISTICS

The stability and control coefficients used in the computer simulation of a free ascent trajectory come from a report on the stability and control characteristics of the Deep Submergence Rescue Vehicle (see ref 15). These coefficients were obtained using a model with propeller running, which violates one of the restrictions originally imposed on the problem. This, however, presents no problem since the coefficients with propeller running can be assumed to represent some fictitious vehicle without propeller running. This fictitious vehicle would be similar to the DSRV but would effectively have additional lifting surface or fin aft.

The coefficients and derivatives, listed in Tables 4, 5, and 6, were experimentally and analytically obtained by NSRDC. These coefficients will be supplimented by the terms which can be estimated from the potential theory of Chapter III (see Table 7).

The drag coefficient, to be used in conjunction with the one dimensional ascent trajectory computation, is obtained from a plot of normal force coefficient as a function of angle of attack found in reference (15). This coefficient is taken as 0.085 at an angle of attack of 90 degrees.

The geometric characteristics, listed in Table 8, are again those for the DSRV and come from reference (15).

The ballast release rates come from reference (5) and are listed in Table 9. The only weights that can be released from the DSRV are the mercury from the trim and roll systems and the water contained in the variable ballast tanks. The mercury must all pass through the central reservoir tank to be dropped, therefore, the mercury release rate is limited to the

release rate from the reservoir. The variable ballast tanks are assumed to be full at the beginning of the ascent since this is the expected operating condition when the vehicle is at depth.

TABLE 4

Vertical - Plane Stability and Control Derivatives

	Ahead	Astern
M_q'	-0.011310	0.011973
Z_q'	-0.017455	0.015420
$M_{\dot{v}}'$	-0.000146	-0.000109
$Z_{\dot{v}}'$	-0.031545	-0.029545
$M_{\dot{q}}'$	-0.001573	-0.001321
$Z_{\dot{q}}'$	-0.000130	-0.000250

TABLE 5

Horizontal - Plane Stability and Control Derivatives

N_r'	-0.012497	-0.014732
Y_r'	0.026955	-0.016795
K_r'	-0.000280	0.000220
$N_{\dot{v}}'$	0.000182	-0.000109
$Y_{\dot{v}}'$	-0.035545	-0.029545
$K_{\dot{v}}'$	0.000190	0.000175
$N_{\dot{r}}'$	-0.001531	-0.001352
$Y_{\dot{r}}'$	0.000400	-0.000250
$K_{\dot{r}}'$	-0.000042	0.000063

Note: Positive direction of body axes considered the same for both ahead and astern motion.

TABLE 6

Stability and Control Coefficients from Curve Fitting and from Statistics

M_*'	0.000021	K_*'	-0.000157
M_w'	0.011175	K_v'	0.002216
$M_{\|w\|}'$	0.001458	$K_{v\|v\|}'$	0.001403
M_{ww}'	-0.003419	K_p'	-0.000067
$M_{w\|w\|}'$	-0.003824	$K_{\dot{p}}'$	-0.000092
M_{vv}'	-0.023017	$K_{p\|p\|}'$	-0.000037
Z_*'	-0.000577	$X_{\dot{u}}'$	-0.001623
Z_w'	-0.043938	X_{uu}'	-0.007442
$Z_{\|w\|}'$	0.003037	X_{vv}'	0.017510
Z_{ww}'	-0.020773	X_{ww}'	0.0[illegible]
$Z_{w\|w\|}'$	-0.060249	Y_v'	-0.067306
Z_{vv}'	-0.032739	$Y_{v\|v\|}'$	-0.173565
N_v'	-0.026053	$N_{v\|v\|}'$	0.036083

TABLE 7

Coefficients Estimated on the Basis of Potential Theory

	Ahead	Astern
X_{qq}	-0.000130	-0.000250
X_{rr}	-0.000400	-0.000280
Y_{vp}	0.031545	0.029545
Y_{pq}	0.000130	0.000250
Z_{vp}	-0.035545	-0.038945
Z_{rp}	0.000400	-0.000280
K_{vw}	0.004000	0.009400
K_{vq}	0.000270	-0.000530
K_{vr}	-0.000270	0.000530
K_{pq}	0.000042	-0.000060
K_{qr}	0.000042	-0.000031
M_{vp}	-0.000400	0.000230
M_{rr}	0.000042	-0.000068
M_{rr}	0.000042	-0.000068
M_{rp}	0.001439	0.000260
N_{vp}	-0.000130	-0.000250
$N_{\dot{p}}$	-0.000042	0.000068
N_{pq}	-0.001481	-0.001229
N_{qr}	0.000042	-0.000068

TABLE 8

GEOMETRIC CHARACTERISTICS

Overall length, ft	49.333
Maximum beam, ft	8.167
Wetted surface area, sq ft	1318.2
Volume, cu ft	2186.1
Displacement of hull form	62.45
Longitudinal distance of CG to FP, ft	23.109
Longitudinal distance of CB to FP, ft	23.109
Height of CG above baseline, ft	3.783
Height of CB above baseline, ft	3.917
Moment of inertia about x - axis, slug - ft^2	31,316.0
Moment of inertia about y - axis, slug - ft^2	560,000.0
Moment of inertia about z - axis, slug - ft^2	560,000.0

TABLE 9

JETTISONABLE BALLAST

TANK	LOCATION (ft)			MAX. WEIGHT	FLOW RATE
	x	y	z	(lb)	(lb/sec)
1	- 3.425	0.0	3.10	2651.3	35.233
2	- 3.425	2.21	-2.24	2651.3	35.233
3	- 3.425	-2.21	-2.24	2651.3	35.233
4	18.9	0.0	-2.816	419.2	10.15
5	-18.6	0.0	-2.458	419.2	10.15
6	12.708	0.0	-2.44	200.0	0.4275
7	-12.308	0.0	-2.26	200.0	0.4275

APPENDIX C

INPUT AND OUTPUT FOR THE VERSION

The following pages contain selected input and output from the computer simulations. Because of the large number of cycles required to simulate a trajectory, it was decided to include only that output necessary to support the conclusions reached in Chapter IV.

C - 1 Arc of Trajectory Run

Time increment during deballasting	.5 sec
Time increment after deballasting	1.0 sec
Initial roll angle	0.0 deg

All ballast removed

```
STEP  DT      TIME      X       Y       Z       PHI     THETA    PSI

  1   0.0      0.0      0.0     0.0     0.0     0.0      0.0     0.0
  2   0.50     0.50     0.0     0.0    -0.0     0.0     -0.00    0.0
  3   0.50     1.00    -0.0     0.0    -0.0     0.0     -0.00    0.0
  4   0.50     1.50    -0.0     0.0    -0.0     0.0     -0.00    0.0
  5   0.50     2.00    -0.0     0.0    -0.0     0.0     -0.00    0.0
  6   0.50     2.50    -0.0     0.0    -0.0     0.0     -0.00    0.0
  7   0.50     3.00    -0.0     0.0    -0.0     0.0     -0.00    0.0
  8   0.50     3.50    -0.0     0.0    -0.0     0.0     -0.00    0.0
  9   0.50     4.00    -0.0     0.0    -0.1     0.0     -0.00    0.0
 10   0.50     4.50    -0.0     0.0    -0.1     0.0     -0.00    0.0
 11   0.50     5.00    -0.0     0.0    -0.1     0.0     -0.00    0.0
 12   0.50     5.50    -0.0     0.0    -0.1     0.0     -0.00    0.0
 13   0.50     6.00    -0.0     0.0    -0.2     0.0     -0.00    0.0
 14   0.50     6.50    -0.0     0.0    -0.2     0.0     -0.00    0.0
 15   0.50     7.00    -0.0     0.0    -0.3     0.0     -0.00    0.0
 16   0.50     7.50    -0.0     0.0    -0.3     0.0     -0.00    0.0
 17   0.50     8.00    -0.0     0.0    -0.4     0.0     -0.00    0.0
 18   0.50     8.50    -0.0     0.0    -0.5     0.0     -0.00    0.0
 19   0.50     9.00    -0.0     0.0    -0.6     0.0     -0.01    0.0
 20   0.50     9.50    -0.0     0.0    -0.7     0.0     -0.01    0.0
 21   0.50    10.00    -0.0     0.0    -0.8     0.0     -0.01    0.0
 22   0.50    10.50    -0.0     0.0    -0.9     0.0     -0.01    0.0
 23   0.50    11.00    -0.0     0.0    -1.1     0.0     -0.01    0.0
 24   0.50    11.50    -0.0     0.0    -1.2     0.0     -0.01    0.0
 25   0.50    12.00    -0.0     0.0    -1.4     0.0     -0.01    0.0
 26   0.50    12.50    -0.0     0.0    -1.5     0.0     -0.01    0.0
 27   0.50    13.00    -0.0     0.0    -1.7     0.0     -0.01    0.0
 28   0.50    13.50    -0.0     0.0    -1.9     0.0     -0.02    0.0
 29   0.50    14.00    -0.0     0.0    -2.1     0.0     -0.02    0.0
 30   0.50    14.50    -0.0     0.0    -2.4     0.0     -0.02    0.0
 31   0.50    15.00    -0.0     0.0    -2.6     0.0     -0.02    0.0
 32   0.50    15.50    -0.0     0.0    -2.9     0.0     -0.02    0.0
 33   0.50    16.00    -0.0     0.0    -3.2     0.0     -0.02    0.0
 34   0.50    16.50    -0.0     0.0    -3.4     0.0     -0.03    0.0
```

STEP	DT	TIME	X	Y	Z	PHI	THETA	PSI
35	0.50	17.00	-0.0	0.0	-3.8	0.0	-0.03	0.0
36	0.50	17.50	-0.1	0.0	-4.1	0.0	-0.03	0.0
37	0.50	18.00	-0.1	0.0	-4.4	0.0	-0.03	0.0
38	0.50	18.50	-0.1	0.0	-4.8	0.0	-0.03	0.0
39	0.50	19.00	-0.1	0.0	-5.2	0.0	-0.04	0.0
40	0.50	19.50	-0.1	0.0	-5.6	0.0	-0.04	0.0
41	0.50	20.00	-0.1	0.0	-6.0	0.0	-0.04	0.0
42	0.50	20.50	-0.1	0.0	-6.5	0.0	-0.04	0.0
43	0.50	21.00	-0.1	0.0	-7.0	0.0	-0.05	0.0
44	0.50	21.50	-0.2	0.0	-7.5	0.0	-0.05	0.0
45	0.50	22.00	-0.2	0.0	-8.0	0.0	-0.05	0.0
46	0.50	22.50	-0.2	0.0	-8.5	0.0	-0.05	0.0
47	0.50	23.00	-0.2	0.0	-9.1	0.0	-0.06	0.0
48	0.50	23.50	-0.2	0.0	-9.7	0.0	-0.06	0.0
49	0.50	24.00	-0.3	0.0	-10.3	0.0	-0.06	0.0
50	0.50	24.50	-0.3	0.0	-10.9	0.0	-0.06	0.0
51	0.50	25.00	-0.3	0.0	-11.5	0.0	-0.07	0.0
52	0.50	25.50	-0.4	0.0	-12.2	0.0	-0.07	0.0
53	0.50	26.00	-0.4	0.0	-12.9	0.0	-0.07	0.0
54	0.50	26.50	-0.5	0.0	-13.7	0.0	-0.07	0.0
55	0.50	27.00	-0.5	0.0	-14.4	0.0	-0.08	0.0
56	0.50	27.50	-0.6	0.0	-15.2	0.0	-0.08	0.0
57	0.50	28.00	-0.6	0.0	-16.0	0.0	-0.08	0.0
58	0.50	28.50	-0.7	0.0	-16.9	0.0	-0.08	0.0
59	0.50	29.00	-0.7	0.0	-17.7	0.0	-0.09	0.0
60	0.50	29.50	-0.9	0.0	-18.5	0.0	-0.09	0.0
61	0.50	30.00	-1.0	0.0	-19.5	0.0	-0.09	0.0
62	0.50	30.50	-1.0	0.0	-20.4	0.0	-0.10	0.0
63	0.50	31.00	-1.0	0.0	-21.3	0.0	-0.10	0.0
64	0.50	31.50	-1.1	0.0	-22.3	0.0	-0.10	0.0
65	0.50	32.00	-1.2	0.0	-23.3	0.0	-0.10	0.0
66	0.50	32.50	-1.3	0.0	-24.4	0.0	-0.10	0.0
67	0.50	33.00	-1.4	0.0	-25.5	0.0	-0.10	0.0
68	0.50	33.50	-1.5	0.0	-26.6	0.0	-0.11	0.0

```
STEP   DT        TIME        X          Y          Z          PHI        THETA       PSI

 171  0.50      85.00      -31.2       0.0      -255.9       0.0       -0.01       0.0
 172  0.50      85.50      -31.7       0.0      -258.9       0.0       -0.02       0.0
 173  0.50      86.00      -32.1       0.0      -261.8       0.0       -0.02       0.0
 174  0.50      86.50      -32.5       0.0      -264.8       0.0       -0.03       0.0
 175  0.50      87.00      -33.0       0.0      -267.8       0.0       -0.04       0.0
 176  0.50      87.50      -33.5       0.0      -270.9       0.0       -0.04       0.0
 177  0.50      88.00      -34.0       0.0      -273.9       0.0       -0.04       0.0
 178  0.50      88.50      -34.5       0.0      -276.9       0.0       -0.05       0.0
 179  0.50      89.00      -35.1       0.0      -280.0       0.0       -0.05       0.0
 180  0.50      89.50      -35.6       0.0      -283.0       0.0       -0.05       0.0
 181  0.50      90.00      -36.2       0.0      -286.1       0.0       -0.05       0.0
 182  0.50      90.50      -36.8       0.0      -289.2       0.0       -0.05       0.0
 183  0.50      91.00      -37.4       0.0      -292.4       0.0       -0.05       0.0
 184  0.50      91.50      -38.0       0.0      -295.6       0.0       -0.05       0.0
 185  0.50      92.00      -38.6       0.0      -298.7       0.0       -0.05       0.0
 186  0.50      92.50      -39.2       0.0      -301.9       0.0       -0.04       0.0
 187  0.50      93.00      -39.8       0.0      -305.1       0.0       -0.04       0.0
 188  0.50      93.50      -40.4       0.0      -308.2       0.0       -0.03       0.0
 189  0.50      94.00      -40.9       0.0      -311.4       0.0       -0.03       0.0
 190  0.50      94.50      -41.4       0.0      -314.6       0.0       -0.02       0.0
 191  0.50      95.00      -42.0       0.0      -317.9       0.0       -0.01       0.0
 192  0.50      95.50      -42.7       0.0      -321.3       0.0       -0.01       0.0
 193  0.50      96.00      -43.2       0.0      -324.5       0.0        0.00       0.0
 194  0.50      96.50      -43.7       0.0      -327.7       0.0        0.01       0.0
 195  0.50      97.00      -44.2       0.0      -331.0       0.0        0.02       0.0
 196  0.50      97.50      -44.7       0.0      -334.2       0.0        0.03       0.0
 197  0.50      98.00      -45.2       0.0      -337.4       0.0        0.03       0.0
 198  0.50      98.50      -45.6       0.0      -340.6       0.0        0.04       0.0
 199  0.50      99.00      -46.0       0.0      -343.8       0.0        0.05       0.0
 200  0.50      99.50      -46.4       0.0      -347.0       0.0        0.05       0.0
 201  0.50     100.00      -46.8       0.0      -350.2       0.0        0.06       0.0
 202  0.50     100.50      -47.1       0.0      -353.4       0.0        0.06       0.0
 203  0.50     101.00      -47.5       0.0      -356.5       0.0        0.06       0.0
 204  0.50     101.50      -47.8       0.0      -359.7       0.0        0.06       0.0
```

STEP	DT	TIME	X	Y	Z	PHI	THETA	PSI
205	0.50	102.00	-48.1	0.0	-362.8	0.0	0.06	0.0
206	0.50	102.50	-48.4	0.0	-365.9	0.0	0.06	0.0
207	0.50	103.00	-48.8	0.0	-369.0	0.0	0.05	0.0
208	0.50	103.50	-49.1	0.0	-372.1	0.0	0.04	0.0
209	0.50	104.00	-49.4	0.0	-375.2	0.0	0.04	0.0
210	0.50	104.50	-49.7	0.0	-378.3	0.0	0.03	0.0
211	0.50	105.00	-50.1	0.0	-381.3	0.0	0.02	0.0
212	0.50	105.50	-50.4	0.0	-384.4	0.0	0.01	0.0
213	0.50	106.00	-50.8	0.0	-387.4	0.0	-0.00	0.0
214	0.50	106.50	-51.3	0.0	-390.5	0.0	-0.01	0.0
215	0.50	107.00	-51.7	0.0	-393.6	0.0	-0.02	0.0
216	0.50	107.50	-52.2	0.0	-396.6	0.0	-0.04	0.0
217	0.50	108.00	-52.7	0.0	-399.7	0.0	-0.05	0.0
218	0.50	108.50	-53.2	0.0	-402.8	0.0	-0.06	0.0
219	0.50	109.00	-53.8	0.0	-406.0	0.0	-0.06	0.0
220	0.50	109.50	-54.4	0.0	-409.1	0.0	-0.07	0.0
221	0.50	110.00	-55.0	0.0	-412.2	0.0	-0.08	0.0
222	0.50	110.50	-55.7	0.0	-415.5	0.0	-0.08	0.0
223	0.50	111.00	-56.3	0.0	-418.7	0.0	-0.08	0.0
224	0.50	111.50	-57.0	0.0	-421.9	0.0	-0.08	0.0
225	0.50	112.00	-57.7	0.0	-425.2	0.0	-0.08	0.0
226	0.50	112.50	-58.5	0.0	-428.5	0.0	-0.08	0.0
227	0.50	113.00	-59.2	0.0	-431.8	0.0	-0.07	0.0
228	0.50	113.50	-59.9	0.0	-435.1	0.0	-0.06	0.0
229	0.50	114.00	-60.7	0.0	-438.4	0.0	-0.05	0.0
230	0.50	114.5	-61.3	0.0	-441.8	0.0	-0.04	0.0
231	0.50	115.00	-62.0	0.0	-445.1	0.0	-0.03	0.0
232	0.50	115.50	-62.6	0.0	-448.5	0.0	-0.02	0.0
233	0.50	116.00	-63.2	0.0	-451.9	0.0	-0.01	0.0
234	0.50	116.5	-63.8	0.0	-455.2	0.0	0.01	0.0
235	1.00	117.50	-64.0	0.0	-461.9	0.0	0.04	0.0
236	1.00	118.50	-65.8	0.0	-468.6	0.0	0.06	0.0
237	1.00	119.50	-66.4	0.0	-475.2	0.0	0.08	0.0
238	1.00	120.50	-67.0	0.0	-481.7	0.0	0.10	0.0

```
STEP  DT      TIME       X        Y        Z       PHI    THETA    PSI

 273  1.00   155.50    -94.2     0.0    -711.4     0.0    -0.27    0.0
 274  1.00   156.50    -96.3     0.0    -719.9     0.0    -0.30    0.0
 275  1.00   157.50    -98.3     0.0    -728.7     0.0    -0.21    0.0
 276  1.00   158.50    -99.9     0.0    -737.6     0.0    -0.11    0.0
 277  1.00   159.50   -101.1     0.0    -746.5     0.0    -0.01    0.0
 278  1.00   160.50   -101.7     0.0    -755.1     0.0     0.10    0.0
 279  1.00   161.50   -101.6     0.0    -763.4     0.0     0.20    0.0
 280  1.00   162.50   -100.7     0.0    -771.5     0.0     0.28    0.0
 281  1.00   163.50    -99.1     0.0    -779.3     0.0     0.33    0.0
 282  1.00   164.50    -97.0     0.0    -786.9     0.0     0.33    0.0
 283  1.00   165.50    -94.9     0.0    -794.0     0.0     0.29    0.0
 284  1.00   166.50    -92.7     0.0    -800.6     0.0     0.21    0.0
 285  1.00   167.50    -90.7     0.0    -805.7     0.0     0.12    0.0
 286  1.00   168.50    -88.9     0.0    -812.4     0.0     0.02    0.0
 287  1.00   169.50    -87.7     0.0    -817.7     0.0    -0.09    0.0
 288  1.00   170.50    -86.9     0.0    -822.9     0.0    -0.20    0.0
 289  1.00   171.50    -86.7     0.0    -827.2     0.0    -0.31    0.0
 290  1.00   172.50    -87.1     0.0    -833.0     0.0    -0.43    0.0
 291  1.00   173.50    -88.1     0.0    -839.0     0.0    -0.52    0.0
 292  1.00   174.50    -89.5     0.0    -845.7     0.0    -0.58    0.0
 293  1.00   175.50    -91.1     0.0    -854.2     0.0    -0.59    0.0
 294  1.00   176.50    -92.8     0.0    -862.2     0.0    -0.56    0.0
 295  1.00   177.50    -94.5     0.0    -871.1     0.0    -0.51    0.0
 296  1.00   178.50    -96.2     0.0    -880.3     0.0    -0.43    0.0
 297  1.00   179.50    -97.7     0.0    -889.2     0.0    -0.33    0.0
 298  1.00   180.50    -98.9     0.0    -899.1     0.0    -0.22    0.0
 299  1.00   181.50    -99.4     0.0    -909.0     0.0    -0.11    0.0
 300  1.00   182.50    -99.7     0.0    -918.3     0.0     0.02    0.0
 301  1.00   183.50    -99.1     0.0    -927.2     0.0     0.14    0.0
 302  1.00   184.50    -97.4     0.0    -935.7     0.0     0.24    0.0
 303  1.00   185.50    -95.0     0.0    -943.8     0.0     0.30    0.0
 304  1.00   186.50    -92.2     0.0    -951.7     0.0     0.31    0.0
 305  1.00   187.50    -89.4     0.0    -959.1     0.0     0.26    0.0
 306  1.00   188.50    -86.5     0.0    -965.9     0.0     0.18    0.0
```

```
STEP   DT      TIME       X        Y        Z        PHI     THETA     PSI

 307  1.00   189.50    -83.9     0.0    -972.0     0.0      0.09     0.0
 308  1.00   190.50    -81.6     0.0    -977.7     0.0     -0.01     0.0
 309  1.00   191.50    -79.7     0.0    -982.9     0.0     -0.12     0.0
 310  1.00   192.50    -78.4     0.0    -988.1     0.0     -0.23     0.0
 311  1.00   193.50    -77.7     0.0    -993.2     0.0     -0.35     0.0
 312  1.00   194.50    -77.4     0.0    -999.7     0.0     -0.47     0.0
 313  1.00   195.50    -77.2     0.0   -1004.7     0.0     -0.56     0.0
 314  1.00   196.50    -79.2     0.0   -1011.4     0.0     -0.62     0.0
 315  1.00   197.50    -80.4     0.0   -1018.8     0.0     -0.64     0.0
 316  1.00   198.50    -81.2     0.0   -1026.9     0.0     -0.62     0.0
 317  1.00   199.50    -83.1     0.0   -1035.6     0.0     -0.57     0.0
 318  1.00   200.50    -84.4     0.0   -1044.8     0.0     -0.49     0.0
 319  1.00   201.50    -85.5     0.0   -1054.4     0.0     -0.40     0.0
 320  1.00   202.50    -86.4     0.0   -1064.1     0.0     -0.29     0.0
 321  1.00   203.50    -86.9     0.0   -1073.7     0.0     -0.17     0.0
 322  1.00   204.50    -86.7     0.0   -1083.1     0.0     -0.05     0.0
 323  1.00   205.50    -86.1     0.0   -1092.2     0.0      0.07     0.0
 324  1.00   206.50    -84.4     0.0   -1100.9     0.0      0.19     0.0
 325  1.00   207.50    -81.9     0.0   -1108.6     0.0      0.26     0.0
 326  1.00   208.50    -78.9     0.0   -1116.9     0.0      0.27     0.0
 327  1.00   209.50    -75.6     0.0   -1124.3     0.0      0.25     0.0
 328  1.00   210.50    -72.5     0.0   -1131.2     0.0      0.18     0.0
 329  1.00   211.50    -68.6     0.0   -1137.4     0.0      0.08     0.0
 330  1.00   212.50    -67.1     0.0   -1142.7     0.0     -0.01     0.0
 331  1.00   213.50    -64.9     0.0   -1148.5     0.0     -0.12     0.0
 332  1.00   214.50    -62.4     0.0   -1153.5     0.0     -0.23     0.0
 333  1.00   215.50    -62.4     0.0   -1158.7     0.0     -0.34     0.0
 334  1.00   216.50    -62.2     0.0   -1164.0     0.0     -0.44     0.0
 335  1.00   217.50    -59.3     0.0   -1169.0     0.0     -0.56     0.0
 336  1.00   218.50    -57.1     0.0   -1176.4     0.0     -0.63     0.0
 337  1.00   219.50    -54.1     0.0   -1183.6     0.0     -0.66     0.0
 338  1.00   220.50    -55.2     0.0   -1191.5     0.0     -0.65     0.0
 339  1.00   221.50    -56.6     0.0   -1200.1     0.0     -0.60     0.0
 340  1.00   222.50    -57.7     0.0   -1208.7     0.0     -0.52     0.0
```

```
STEP   DT        TIME          X           Y          Z          PHI       THETA       PSI

409   1.00     201.50      -13.7        0.0    -1730.2        0.0       -0.32        0.0
410   1.00     202.50      -14.1        0.0    -1732.9        0.0       -0.20        0.0
411   1.00     203.50      -14.2        0.0    -1740.2        0.0       -0.08        0.0
412   1.00     204.50      -13.2        0.0    -1759.4        0.0        0.04        0.0
413   1.00     205.50      -11.5        0.0    -1767.0        0.0        0.16        0.0
414   1.00     206.50       -9.0        0.0    -1775.2        0.0        0.24        0.0
415   1.00     207.50       -5.8        0.0    -1782.1        0.0        0.27        0.0
416   1.00     208.50       -2.5        0.0    -1790.5        0.0        0.25        0.0
417   1.00     209.50        0.7        0.0    -1797.4        0.0        0.19        0.0
418   1.00     210.50        3.7        0.0    -1805.7        0.0        0.09        0.0
```

```
 STEP    TIME       H         V         W         P         Q         R
                  EARTH     EARTH     EARTH     EARTH     EARTH     EARTH

    1    0.0       0.0       0.0       0.0       0.0       0.0       0.0
    2    0.50      0.0       0.0      -0.001     0.0      -0.000     0.0
    3    1.00     -0.000     0.0      -0.003     0.0      -0.000     0.0
    4    1.50     -0.000     0.0      -0.007     0.0      -0.000     0.0
    5    2.00     -0.000     0.0      -0.011     0.0      -0.000     0.0
    6    2.50     -0.000     0.0      -0.017     0.0      -0.000     0.0
    7    3.00     -0.000     0.0      -0.023     0.0      -0.000     0.0
    8    3.50     -0.000     0.0      -0.031     0.0      -0.000     0.0
    9    4.00     -0.000     0.0      -0.040     0.0      -0.000     0.0
   10    4.50     -0.000     0.0      -0.050     0.0      -0.000     0.0
   11    5.00     -0.000     0.0      -0.061     0.0      -0.001     0.0
   12    5.50     -0.000     0.0      -0.073     0.0      -0.001     0.0
   13    6.00     -0.000     0.0      -0.087     0.0      -0.001     0.0
   14    6.50     -0.000     0.0      -0.101     0.0      -0.001     0.0
   15    7.00     -0.000     0.0      -0.117     0.0      -0.001     0.0
   16    7.50     -0.000     0.0      -0.133     0.0      -0.001     0.0
   17    8.00     -0.000     0.0      -0.151     0.0      -0.001     0.0
   18    8.50     -0.001     0.0      -0.170     0.0      -0.002     0.0
   19    9.00     -0.001     0.0      -0.190     0.0      -0.002     0.0
   20    9.50     -0.001     0.0      -0.211     0.0      -0.002     0.0
   21   10.00     -0.001     0.0      -0.233     0.0      -0.002     0.0
   22   10.50   [illegible]  0.0      -0.256     0.0      -0.002     0.0
   23   11.00     -0.002     0.0      -0.280     0.0      -0.002     0.0
   24   11.50     -0.002     0.0      -0.305     0.0      -0.003     0.0
   25   12.00     -0.003     0.0      -0.331     0.0      -0.003     0.0
   26   12.50   [illegible]  0.0      -0.358     0.0      -0.003     0.0
   27   13.00     -0.004     0.0      -0.387     0.0      -0.003     0.0
   28   13.50   [illegible]  0.0      -0.416     0.0      -0.003     0.0
   29   14.00     -0.006     0.0      -0.446     0.0      -0.003     0.0
   30   14.50     -0.007     0.0      -0.477     0.0      -0.003     0.0
   31   15.00     -0.008     0.0      -0.509     0.0      -0.004     0.0
   32   15.50     -0.010     0.0      -0.541     0.0      -0.004     0.0
   33   16.00     -0.011     0.0      -0.577     0.0      -0.004     0.0
   34   16.50   [illegible]  0.0      -0.611     0.0      -0.004     0.0
```

```
  STEP     TIME       U          V          W          P          Q          R
                    EARTH      EARTH      EARTH      EARTH      EARTH      EARTH

   35     17.00     -0.014      0.0      -0.643      0.0      -0.004      0.0
   36     17.50     -0.016      0.0      -0.684      0.0      -0.004      0.0
   37     18.00     -0.019      0.0      -0.722      0.0      -0.004      0.0
   38     18.50     -0.020      0.0      -0.760      0.0      -0.004      0.0
   39     19.00     -0.023      0.0      -0.800      0.0      -0.004      0.0
   40     19.50     -0.026      0.0      -0.840      0.0      -0.004      0.0
   41     20.00     -0.029      0.0      -0.881      0.0      -0.004      0.0
   42     20.50     -0.032      0.0      -0.923      0.0      -0.005      0.0
   43     21.00     -0.035      0.0      -0.965      0.0      -0.005      0.0
   44     21.50     -0.038      0.0      -1.008      0.0      -0.005      0.0
   45     22.00     -0.043      0.0      -1.052      0.0      -0.005      0.0
   46     22.50     -0.047      0.0      -1.097      0.0      -0.005      0.0
   47     23.00     -0.051      0.0      -1.142      0.0      -0.005      0.0
   48     23.50     -0.055      0.0      -1.190      0.0      -0.005      0.0
   49     24.00     -0.061      0.0      -1.238      0.0      -0.005      0.0
   50     24.50     -0.067      0.0      -1.282      0.0      -0.005      0.0
   51     25.00     -0.072      0.0      -1.330      0.0      -0.005      0.0
   52     25.50     -0.078      0.0      -1.376      0.0      -0.005      0.0
   53     26.00     -0.085      0.0      -1.423      0.0      -0.005      0.0
   54     26.50     -0.092      0.0      -1.473      0.0      -0.005      0.0
   55     27.00     -0.100      0.0      -1.520      0.0      -0.005      0.0
   56     27.50     -0.107      0.0      -1.570      0.0      -0.005      0.0
   57     28.00     -0.115      0.0      -1.620      0.0      -0.005      0.0
   58     28.50     -0.122      0.0      -1.672      0.0      -0.005      0.0
   59     29.00     -0.132      0.0      -1.724      0.0      -0.005      0.0
   60     29.50     -0.141      0.0      -1.777      0.0      -0.005      0.0
   61     30.00     -0.150      0.0      -1.830      0.0      -0.005      0.0
   62     30.50     -0.160      0.0      -1.884      0.0      -0.005      0.0
   63     31.00     -0.171      0.0      -1.940      0.0      -0.005      0.0
   64     31.50     -0.180      0.0      -2.000      0.0      -0.004      0.0
   65     32.00     -0.191      0.0      -2.057      0.0      -0.004      0.0
   66     32.50     -0.202      0.0      -2.116      0.0      -0.004      0.0
   67     33.00     -0.212      0.0      -2.170      0.0      -0.004      0.0
   68     33.50     -0.224      0.0      -2.233      0.0      -0.005      0.0
```

STEP	TIME	J EARTH	V EARTH	W EARTH	P EARTH	Q EARTH	R EARTH
205	102.00	-0.632	0.0	-6.230	0.0	-0.004	0.0
206	102.50	-0.625	0.0	-6.213	0.0	-0.007	0.0
207	103.00	-0.627	0.0	-6.189	0.0	-0.010	0.0
208	103.50	-0.634	0.0	-6.160	0.0	-0.013	0.0
209	104.00	-0.655	0.0	-6.142	0.0	-0.016	0.0
210	104.50	-0.681	0.0	-6.133	0.0	-0.018	0.0
211	105.00	-0.716	0.0	-6.125	0.0	-0.020	0.0
212	105.50	-0.759	0.0	-6.121	0.0	-0.021	0.0
213	106.00	-0.808	0.0	-6.123	0.0	-0.022	0.0
214	106.50	-0.863	0.0	-6.131	0.0	-0.022	0.0
215	107.00	-0.922	0.0	-6.144	0.0	-0.023	0.0
216	107.50	-0.985	0.0	-6.167	0.0	-0.022	0.0
217	108.00	-1.043	0.0	-6.190	0.0	-0.020	0.0
218	108.50	-1.111	0.0	-6.229	0.0	-0.019	0.0
219	109.00	-1.172	0.0	-6.267	0.0	-0.016	0.0
220	109.50	-1.227	0.0	-6.310	0.0	-0.013	0.0
221	110.00	-1.271	0.0	-6.357	0.0	-0.009	0.0
222	110.50	-1.327	0.0	-6.405	0.0	-0.006	0.0
223	111.00	-1.365	0.0	-6.454	0.0	-0.002	0.0
224	111.50	-1.397	0.0	-6.502	0.0	0.002	0.0
225	112.00	-1.410	0.0	-6.548	0.0	0.006	0.0
226	112.50	-1.420	0.0	-6.591	0.0	0.010	0.0
227	113.00	-1.431	0.0	-6.629	0.0	0.013	0.0
228	113.50	-1.433	0.0	-6.661	0.0	0.017	0.0
229	114.00	-1.424	0.0	-6.690	0.0	0.020	0.0
230	114.50	-1.375	0.0	-6.707	0.0	0.022	0.0
231	115.00	-1.337	0.0	-6.719	0.0	0.024	0.0
232	115.50	-1.288	0.0	-6.725	0.0	0.026	0.0
233	116.00	-1.223	0.0	-6.724	0.0	0.027	0.0
234	116.50	-1.109	0.0	-6.715	0.0	0.028	0.0
235	117.50	-0.977	0.0	-6.702	0.0	0.027	0.0
236	118.50	-0.774	0.0	-6.645	0.0	0.025	0.0
237	119.50	-0.606	0.0	-6.560	0.0	0.021	0.0
238	120.50	-0.440	0.0	-6.475	0.0	0.014	0.0

STEP	TIME	U BODY	V BODY	W BODY	P BODY	Q BODY	R BODY
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.50	0.0	0.0	-0.001	0.0	-0.000	0.0
3	1.00	-0.000	0.0	-0.003	0.0	-0.000	0.0
4	1.50	-0.000	0.0	-0.007	0.0	-0.000	0.0
5	2.00	-0.000	0.0	-0.011	0.0	-0.000	0.0
6	2.50	-0.000	0.0	-0.017	0.0	-0.000	0.0
7	3.00	-0.000	0.0	-0.023	0.0	-0.000	0.0
8	3.50	-0.000	0.0	-0.031	0.0	-0.000	0.0
9	4.00	-0.000	0.0	-0.040	0.0	-0.000	0.0
10	4.50	-0.000	0.0	-0.050	0.0	-0.000	0.0
11	5.00	-0.000	0.0	-0.061	0.0	-0.000	0.0
12	5.50	-0.000	0.0	-0.073	0.0	-0.001	0.0
13	6.00	-0.000	0.0	-0.087	0.0	-0.001	0.0
14	6.50	-0.000	0.0	-0.101	0.0	-0.001	0.0
15	7.00	-0.000	0.0	-0.117	0.0	-0.001	0.0
16	7.50	-0.001	0.0	-0.133	0.0	-0.001	0.0
17	8.00	-0.001	0.0	-0.151	0.0	-0.001	0.0
18	8.50	-0.001	0.0	-0.170	0.0	-0.002	0.0
19	9.00	-0.002	0.0	-0.190	0.0	-0.002	0.0
20	9.50	-0.002	0.0	-0.211	0.0	-0.002	0.0
21	10.00	-0.003	0.0	-0.232	0.0	-0.002	0.0
22	10.50	-0.003	0.0	-0.255	0.0	-0.002	0.0
23	11.00	-0.004	0.0	-0.280	0.0	-0.002	0.0
24	11.50	-0.005	0.0	-0.305	0.0	-0.002	0.0
25	12.00	-0.006	0.0	-0.331	0.0	-0.003	0.0
26	12.50	-0.007	0.0	-0.358	0.0	-0.003	0.0
27	13.00	-0.009	0.0	-0.387	0.0	-0.003	0.0
28	13.50	-0.011	0.0	-0.416	0.0	-0.003	0.0
29	14.00	-0.013	0.0	-0.444	0.0	-0.003	0.0
30	14.50	-0.015	0.0	-0.477	0.0	-0.003	0.0
31	15.00	-0.018	0.0	-0.509	0.0	-0.004	0.0
32	15.50	-0.021	0.0	-0.547	0.0	-0.004	0.0
33	16.00	-0.024	0.0	-0.576	0.0	-0.004	0.0
34	16.50	-0.027	0.0	-0.611	0.0	-0.004	0.0

STEP	TIME	U BODY	V BODY	W BODY	P BODY	Q BODY	R BODY
35	17.00	-0.031	0.0	-0.647	0.0	-0.004	0.0
36	17.50	-0.038	0.0	-0.684	0.0	-0.004	0.0
37	18.00	-0.040	0.0	-0.721	0.0	-0.004	0.0
38	18.50	-0.045	0.0	-0.758	0.0	-0.004	0.0
39	19.00	-0.050	0.0	-0.795	0.0	-0.004	0.0
40	19.50	-0.057	0.0	-0.833	0.0	-0.004	0.0
41	20.00	-0.063	0.0	-0.870	0.0	-0.004	0.0
42	20.50	-0.07	0.0	-0.921	0.0	-0.005	0.0
43	21.00	-0.077	0.0	-0.963	0.0	-0.005	0.0
44	21.50	-0.085	0.0	-1.002	0.0	-0.005	0.0
45	22.00	-0.093	0.0	-1.040	0.0	-0.005	0.0
46	22.50	-0.102	0.0	-1.083	0.0	-0.005	0.0
47	23.00	-0.112	0.0	-1.128	0.0	-0.005	0.0
48	23.50	-0.122	0.0	-1.163	0.0	-0.005	0.0
49	24.00	-0.133	0.0	-1.222	0.0	-0.005	0.0
50	24.50	-0.144	0.0	-1.273	0.0	-0.005	0.0
51	25.00	-0.155	0.0	-1.322	0.0	-0.005	0.0
52	25.50	-0.166	0.0	-1.371	0.0	-0.005	0.0
53	26.00	-0.177	0.0	-1.419	0.0	-0.005	0.0
54	26.50	-0.196	0.0	-1.467	0.0	-0.005	0.0
55	27.00	-0.211	0.0	-1.516	0.0	-0.005	0.0
56	27.50	-0.225	0.0	-1.565	0.0	-0.005	0.0
57	28.00	-0.242	0.0	-1.616	0.0	-0.005	0.0
58	28.50	-0.260	0.0	-1.664	0.0	-0.005	0.0
59	29.00	-0.277	0.0	-1.717	0.0	-0.005	0.0
60	29.50	-0.295	0.0	-1.769	0.0	-0.005	0.0
61	30.00	-0.313	0.0	-1.819	0.0	-0.005	0.0
62	30.50	-0.332	0.0	-1.871	0.0	-0.005	0.0
63	31.00	-0.352	0.0	-1.922	0.0	-0.005	0.0
64	31.50	-0.372	0.0	-1.974	0.0	-0.004	0.0
65	32.00	-0.392	0.0	-2.022	0.0	-0.004	0.0
66	32.50	-0.412	0.0	-2.071	0.0	-0.004	0.0
67	33.00	-0.433	0.0	-2.125	0.0	-0.004	0.0
68	33.50	-0.454	0.0	-2.175	0.0	-0.003	0.0

STEP	TIME	U BODY	V BODY	W BODY	P BODY	Q BODY	R BODY
171	85.00	-0.975	0.0	-5.881	0.0	-0.011	0.0
172	85.50	-1.034	0.0	-5.902	0.0	-0.011	0.0
173	86.00	-1.091	0.0	-5.922	0.0	-0.011	0.0
174	86.50	-1.163	0.0	-5.946	0.0	-0.011	0.0
175	87.00	-1.195	0.0	-5.972	0.0	-0.010	0.0
176	87.50	-1.242	0.0	-5.999	0.0	-0.009	0.0
177	88.00	-1.290	0.0	-6.028	0.0	-0.008	0.0
178	88.50	-1.323	0.0	-6.058	0.0	-0.007	0.0
179	89.00	-1.385	0.0	-6.089	0.0	-0.005	0.0
180	89.50	-1.424	0.0	-6.121	0.0	-0.003	0.0
181	90.00	-1.474	0.0	-6.154	0.0	-0.001	0.0
182	90.50	-1.505	0.0	-6.188	0.0	0.001	0.0
183	91.00	-1.523	0.0	-6.223	0.0	0.003	0.0
184	91.50	-1.533	0.0	-6.257	0.0	0.005	0.0
185	92.00	-1.530	0.0	-6.291	0.0	0.007	0.0
186	92.50	-1.514	0.0	-6.324	0.0	0.009	0.0
187	93.00	-1.486	0.0	-6.356	0.0	0.011	0.0
188	93.50	-1.446	0.0	-6.387	0.0	0.012	0.0
189	94.00	-1.395	0.0	-6.411	0.0	0.014	0.0
190	94.50	-1.333	0.0	-6.432	0.0	0.015	0.0
191	95.00	-1.261	0.0	-6.450	0.0	0.016	0.0
192	95.50	-1.182	0.0	-6.464	0.0	0.016	0.0
193	96.00	-1.095	0.0	-6.473	0.0	0.016	0.0
194	96.50	-1.004	0.0	-6.477	0.0	0.016	0.0
195	97.00	-0.912	0.0	-6.476	0.0	0.016	0.0
196	97.50	-0.815	0.0	-6.469	0.0	0.015	0.0
197	98.00	-0.721	0.0	-6.458	0.0	0.014	0.0
198	98.50	-0.631	0.0	-6.443	0.0	0.013	0.0
199	99.00	-0.546	0.0	-6.424	0.0	0.011	0.0
200	99.50	-0.467	0.0	-6.402	0.0	0.009	0.0
201	100.00	-0.401	0.0	-6.377	0.0	0.007	0.0
202	100.50	-0.345	0.0	-6.350	0.0	0.004	0.0
203	101.00	-0.307	0.0	-6.322	0.0	0.001	0.0
204	101.50	-0.273	0.0	-6.293	0.0	-0.001	0.0

STEP	TIME	U BODY	V BODY	W BODY	P BODY	Q BODY	R BODY
205	102.00	-0.260	0.0	-6.266	0.0	-0.004	0.0
206	102.50	-0.263	0.0	-6.239	0.0	-0.007	0.0
207	103.00	-0.294	0.0	-6.214	0.0	-0.010	0.0
208	103.50	-0.322	0.0	-6.192	0.0	-0.013	0.0
209	104.00	-0.378	0.0	-6.173	0.0	-0.016	0.0
210	104.50	-0.450	0.0	-6.157	0.0	-0.018	0.0
211	105.00	-0.537	0.0	-6.144	0.0	-0.020	0.0
212	105.50	-0.622	0.0	-6.135	0.0	-0.021	0.0
213	106.00	-0.751	0.0	-6.130	0.0	-0.022	0.0
214	106.50	-0.873	0.0	-6.130	0.0	-0.023	0.0
215	107.00	-1.002	0.0	-6.133	0.0	-0.023	0.0
216	107.50	-1.124	0.0	-6.141	0.0	-0.022	0.0
217	108.00	-1.265	0.0	-6.154	0.0	-0.020	0.0
218	108.50	-1.396	0.0	-6.171	0.0	-0.018	0.0
219	109.00	-1.510	0.0	-6.192	0.0	-0.016	0.0
220	109.50	-1.629	0.0	-6.219	0.0	-0.013	0.0
221	110.00	-1.729	0.0	-6.246	0.0	-0.010	0.0
222	110.50	-1.814	0.0	-6.275	0.0	-0.006	0.0
223	111.00	-1.870	0.0	-6.327	0.0	-0.002	0.0
224	111.50	-1.923	0.0	-6.367	0.0	0.002	0.0
225	112.00	-1.964	0.0	-6.410	0.0	0.006	0.0
226	112.50	-1.951	0.0	-6.453	0.0	0.010	0.0
227	113.00	-1.922	0.0	-6.501	0.0	0.013	0.0
228	113.50	-1.878	0.0	-6.540	0.0	0.017	0.0
229	114.00	-1.818	0.0	-6.587	0.0	0.020	0.0
230	114.50	-1.721	0.0	-6.627	0.0	0.022	0.0
231	115.00	-1.624	0.0	-6.657	0.0	0.024	0.0
232	115.50	-1.495	0.0	-6.682	0.0	0.026	0.0
233	116.00	-1.352	0.0	-6.701	0.0	0.027	0.0
234	116.50	-1.215	0.0	-6.709	0.0	0.028	0.0
235	117.50	-0.902	0.0	-6.707	0.0	0.028	0.0
236	118.50	-0.510	0.0	-6.667	0.0	0.025	0.0
237	119.50	-0.175	0.0	-6.593	0.0	0.021	0.0
238	120.50	0.177	0.0	-6.490	0.0	0.014	0.0

STEP	TIME	U BODY	V BODY	W BODY	P BODY	Q BODY	R BODY
307	189.50	3.513	0.0	-5.219	0.0	-0.099	0.0
308	190.50	2.578	0.0	-5.216	0.0	-0.107	0.0
309	191.50	1.541	0.0	-5.167	0.0	-0.111	0.0
310	192.50	0.475	0.0	-5.171	0.0	-0.116	0.0
311	193.50	-0.642	0.0	-5.220	0.0	-0.120	0.0
312	194.50	-2.121	0.0	-5.233	0.0	-0.111	0.0
313	195.50	-3.579	0.0	-5.258	0.0	-0.092	0.0
314	196.50	-4.751	0.0	-5.310	0.0	-0.042	0.0
315	197.50	-5.635	0.0	-5.513	0.0	0.003	0.0
316	198.50	-6.159	0.0	-5.820	0.0	0.040	0.0
317	199.50	-6.317	0.0	-6.542	0.0	0.047	0.0
318	200.50	-6.112	0.0	-7.290	0.0	0.096	0.0
319	201.50	-5.402	0.0	-8.005	0.0	0.102	0.0
320	202.50	-4.463	0.0	-8.640	0.0	0.114	0.0
321	203.50	-3.024	0.0	-9.104	0.0	0.122	0.0
322	204.50	-1.244	0.0	-9.170	0.0	0.125	0.0
323	205.50	0.716	0.0	-9.251	0.0	0.122	0.0
324	206.50	2.730	0.0	-8.104	0.0	0.103	0.0
325	207.50	4.216	0.0	-7.290	0.0	[illegible]	0.0
326	208.50	5.141	0.0	-6.462	0.0	-0.031	0.0
327	209.50	5.172	0.0	-5.999	0.0	-0.057	0.0
328	210.50	4.611	0.0	-5.560	0.0	-0.092	0.0
329	211.50	3.766	0.0	-5.377	0.0	-0.097	0.0
330	212.50	2.027	0.0	-5.223	0.0	-0.105	0.0
331	213.50	1.011	0.0	-5.166	0.0	-0.113	0.0
332	214.50	0.021	0.0	-5.170	0.0	-0.114	0.0
333	215.50	-0.512	0.0	-5.190	0.0	-0.119	0.0
334	216.50	-1.341	0.0	-5.241	0.0	-0.114	0.0
335	217.50	-2.224	0.0	-5.240	0.0	-0.098	0.0
336	218.50	-4.471	0.0	-5.270	0.0	-0.050	0.0
337	219.50	-5.138	0.0	-5.483	0.0	-0.006	0.0
338	220.50	-6.046	0.0	-5.901	0.0	0.030	0.0
339	221.50	-6.200	0.0	-6.370	0.0	0.061	0.0
340	222.50	-6.112	0.0	-7.002	0.0	0.092	0.0

STEP	TIME	U BODY	V BODY	W BODY	P BODY	Q BODY	R BODY
409	291.50	-4.591	0.0	-9.602	0.0	0.113	0.0
410	292.50	-3.186	0.0	-9.251	0.0	0.121	0.0
411	293.50	-1.442	0.0	-9.147	0.0	0.125	0.0
412	294.50	0.478	0.0	-8.891	0.0	0.124	0.0
413	295.50	2.493	0.0	-8.267	0.0	0.100	0.0
414	296.50	4.210	0.0	-7.474	0.0	0.059	0.0
415	297.50	5.119	0.0	-6.679	0.0	-0.003	0.0
416	298.50	5.156	0.0	-6.049	0.0	-0.052	0.0
417	299.50	4.659	0.0	-5.628	0.0	-0.086	0.0
418	300.50	2.306	0.0	-5.371	0.0	-0.095	0.0

STEP	TIME	U DOT	V DOT	W DOT	P DOT	Q DOT	R DOT
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.50	[illegible]	0.0	-0.002	0.0	-0.000	0.0
3	1.00	-0.000	0.0	-0.004	0.0	-0.000	0.0
4	1.50	-0.000	0.0	-0.007	0.0	-0.000	0.0
5	2.00	-0.000	0.0	-0.009	0.0	-0.000	0.0
6	2.50	-0.000	0.0	-0.011	0.0	-0.000	0.0
7	3.00	[illegible]	0.0	-0.013	0.0	-0.000	0.0
8	3.50	-0.000	0.0	-0.016	0.0	-0.000	0.0
9	4.00	-0.000	0.0	-0.018	0.0	-0.000	0.0
10	4.50	-0.000	0.0	-0.020	0.0	-0.000	0.0
11	5.00	-0.000	0.0	-0.022	0.0	-0.000	0.0
12	5.50	-0.000	0.0	-0.024	0.0	-0.000	0.0
13	6.00	-0.000	0.0	-0.027	0.0	-0.000	0.0
14	6.50	-0.000	0.0	-0.029	0.0	-0.000	0.0
15	7.00	[illegible]	0.0	-0.031	0.0	-0.000	0.0
16	7.50	[illegible]	0.0	-0.033	0.0	-0.000	0.0
17	8.00	-0.000	0.0	[illegible]	0.0	-0.000	0.0
18	8.50	-0.001	0.0	-0.038	0.0	-0.000	0.0
19	9.00	-0.001	0.0	-0.040	0.0	-0.000	0.0
20	9.50	-0.001	0.0	-0.042	0.0	-0.000	0.0
21	10.00	-0.001	0.0	-0.044	0.0	-0.000	0.0
22	10.50	-0.001	0.0	-0.046	0.0	-0.000	0.0
23	11.00	-0.002	0.0	[illegible]	0.0	-0.000	0.0
24	11.50	-0.002	0.0	[illegible]	0.0	-0.000	0.0
25	12.00	-0.002	0.0	[illegible]	0.0	-0.000	0.0
26	12.50	-0.003	0.0	[illegible]	0.0	-0.000	0.0
27	13.00	-0.003	0.0	[illegible]	0.0	-0.000	0.0
28	13.50	-0.004	0.0	[illegible]	0.0	-0.000	0.0
29	14.00	-0.004	0.0	[illegible]	0.0	-0.000	0.0
30	14.50	-0.005	0.0	-0.062	0.0	-0.000	0.0
31	15.00	-0.005	0.0	-0.064	0.0	-0.000	0.0
32	15.50	-0.006	0.0	-0.066	0.0	-0.000	0.0
33	16.00	[illegible]	0.0	-0.068	0.0	-0.000	0.0
34	16.50	-0.007	0.0	[illegible]	0.0	-0.000	0.0

STEP	TIME	U DOT	V DOT	W DOT	P DOT	Q DOT	R DOT
35	17.00	-0.008	0.0	-0.072	0.0	-0.000	0.0
36	17.50	-0.008	0.0	-0.073	0.0	-0.000	0.0
37	18.00	-0.009	0.0	-0.075	0.0	-0.000	0.0
38	18.50	-0.010	0.0	-0.077	0.0	-0.000	0.0
39	19.00	-0.011	0.0	-0.078	0.0	-0.000	0.0
40	19.50	-0.012	0.0	-0.080	0.0	-0.000	0.0
41	20.00	-0.013	0.0	-0.081	0.0	-0.000	0.0
42	20.50	-0.014	0.0	-0.083	0.0	-0.000	0.0
43	21.00	-0.015	0.0	-0.084	0.0	-0.000	0.0
44	21.50	-0.016	0.0	-0.086	0.0	-0.000	0.0
45	22.00	-0.017	0.0	-0.087	0.0	-0.000	0.0
46	22.50	-0.018	0.0	-0.088	0.0	-0.000	0.0
47	23.00	-0.019	0.0	-0.090	0.0	-0.000	0.0
48	23.50	-0.021	0.0	-0.091	0.0	-0.000	0.0
49	24.00	-0.022	0.0	-0.092	0.0	-0.000	0.0
50	24.50	-0.023	0.0	-0.093	0.0	-0.000	0.0
51	25.00	-0.024	0.0	-0.094	0.0	-0.000	0.0
52	25.50	-0.025	0.0	-0.095	0.0	-0.000	0.0
53	26.00	-0.027	0.0	-0.096	0.0	-0.000	0.0
54	26.50	-0.028	0.0	-0.097	0.0	-0.000	0.0
55	27.00	-0.029	0.0	-0.098	0.0	0.000	0.0
56	27.50	-0.031	0.0	-0.099	0.0	0.000	0.0
57	28.00	-0.032	0.0	-0.100	0.0	0.000	0.0
58	28.50	-0.033	0.0	-0.101	0.0	0.000	0.0
59	29.00	-0.035	0.0	-0.101	0.0	0.000	0.0
60	29.50	-0.036	0.0	-0.102	0.0	0.000	0.0
61	30.00	-0.037	0.0	-0.103	0.0	0.000	0.0
62	30.50	-0.038	0.0	-0.104	0.0	0.000	0.0
63	31.00	-0.039	0.0	-0.104	0.0	0.000	0.0
64	31.50	-0.040	0.0	-0.105	0.0	0.000	0.0
65	32.00	-0.041	0.0	-0.105	0.0	0.000	0.0
66	32.50	-0.041	0.0	-0.105	0.0	0.001	0.0
67	33.00	-0.042	0.0	-0.106	0.0	0.001	0.0
68	33.50	-0.042	0.0	-0.106	0.0	0.001	0.0

STEP	TIME	U DOT	V DOT	W DOT	P DOT	Q DOT	R DOT
171	85.00	-0.112	0.0	-0.035	0.0	-0.001	0.0
172	85.50	-0.122	0.0	-0.039	0.0	-0.000	0.0
173	86.00	-0.129	0.0	-0.043	0.0	0.000	0.0
174	86.50	-0.134	0.0	-0.048	0.0	0.001	0.0
175	87.00	-0.136	0.0	-0.052	0.0	0.001	0.0
176	87.50	-0.135	0.0	-0.055	0.0	0.002	0.0
177	88.00	-0.130	0.0	-0.057	0.0	0.002	0.0
178	88.50	-0.122	0.0	-0.060	0.0	0.003	0.0
179	89.00	-0.112	0.0	-0.062	0.0	0.003	0.0
180	89.50	[illegible]	0.0	-0.065	0.0	0.004	0.0
181	90.00	-0.081	0.0	-0.067	0.0	0.004	0.0
182	90.50	-0.061	0.0	-0.068	0.0	0.004	0.0
183	91.00	[illegible]	0.0	-0.069	0.0	0.004	0.0
184	91.50	-0.017	0.0	-0.069	0.0	0.004	0.0
185	92.00	0.007	0.0	-0.068	0.0	0.004	0.0
186	92.50	0.031	0.0	-0.065	0.0	0.004	0.0
187	93.00	0.056	0.0	-0.062	0.0	0.004	0.0
188	93.50	[illegible]	0.0	-0.057	0.0	0.003	0.0
189	94.00	0.103	0.0	-0.052	0.0	0.002	0.0
190	94.50	0.124	0.0	-0.045	0.0	0.002	0.0
191	95.00	0.141	0.0	-0.037	0.0	0.002	0.0
192	95.50	0.158	0.0	-0.028	0.0	0.001	0.0
193	96.00	0.173	0.0	-0.019	0.0	0.001	0.0
194	96.50	[illegible]	0.0	-0.005	0.0	-0.000	0.0
195	97.00	[illegible]	0.0	0.002	0.0	-0.001	0.0
196	97.50	[illegible]	0.0	0.012	0.0	-0.001	0.0
197	98.00	0.187	0.0	0.028	0.0	-0.002	0.0
198	98.50	0.181	0.0	[illegible]	0.0	-0.003	0.0
199	99.00	0.170	0.0	[illegible]	0.0	-0.003	0.0
200	99.50	0.155	0.0	0.045	0.0	-0.004	0.0
201	100.00	0.135	0.0	0.050	0.0	-0.005	0.0
202	100.50	0.112	0.0	0.054	0.0	-0.005	0.0
203	101.00	0.087	0.0	0.056	0.0	-0.005	0.0
204	101.50	0.057	0.0	0.057	0.0	-0.006	0.0

STEP	TIME	U DOT	V DOT	W DOT	P DOT	Q DOT	R DOT
205	102.00	0.024	0.0	0.056	0.0	-0.006	0.0
206	102.50	-0.007	0.0	0.053	0.0	-0.006	0.0
207	103.00	-0.042	0.0	0.049	0.0	-0.006	0.0
208	103.50	-0.077	0.0	0.045	0.0	-0.006	0.0
209	104.00	-0.111	0.0	0.039	0.0	-0.005	0.0
210	104.50	-0.144	0.0	0.032	0.0	-0.005	0.0
211	105.00	-0.176	0.0	0.025	0.0	-0.004	0.0
212	105.50	-0.202	0.0	[illegible]	0.0	-0.003	0.0
213	106.00	-0.226	0.0	0.011	0.0	-0.002	0.0
214	106.50	-0.244	0.0	0.001	0.0	-0.001	0.0
215	107.00	-0.257	0.0	[illegible]	0.0	[illegible]	0.0
216	107.50	-0.264	0.0	-0.014	0.0	0.002	0.0
217	108.00	-0.265	0.0	-0.025	0.0	0.003	0.0
218	108.50	-0.252	0.0	-0.034	0.0	0.004	0.0
219	109.00	[illegible]	0.0	-0.041	0.0	0.005	0.0
220	109.50	-0.225	0.0	-0.053	0.0	0.006	0.0
221	110.00	[illegible]	0.0	-0.067	0.0	0.007	0.0
222	110.50	[illegible]	0.0	[illegible]	0.0	0.007	0.0
223	111.00	-0.131	0.0	-0.079	0.0	0.007	0.0
224	111.50	[illegible]	0.0	[illegible]	0.0	0.008	0.0
225	112.00	[illegible]	0.0	[illegible]	0.0	0.008	0.0
226	112.50	[illegible]	0.0	-0.091	0.0	0.008	0.0
227	113.00	[illegible]	0.0	-0.091	0.0	0.007	0.0
228	113.50	[illegible]	0.0	[illegible]	0.0	0.007	0.0
229	114.00	[illegible]	0.0	[illegible]	0.0	0.006	0.0
230	114.50	0.174	0.0	[illegible]	0.0	0.005	0.0
231	115.00	0.216	0.0	[illegible]	0.0	0.004	0.0
232	115.50	[illegible]	0.0	[illegible]	0.0	0.003	0.0
233	116.00	[illegible]	0.0	[illegible]	0.0	0.002	0.0
234	116.50	0.305	0.0	-0.012	0.0	0.001	0.0
235	117.00	0.324	0.0	0.001	0.0	[illegible]	0.0
236	117.50	0.347	0.0	[illegible]	0.0	[illegible]	0.0
237	118.00	[illegible]	0.0	[illegible]	0.0	[illegible]	0.0
238	118.50	[illegible]	0.0	[illegible]	0.0	-0.007	0.0

STEP	TIME	U DOT	V DOT	W DOT	P DOT	Q DOT	R DOT
273	155.50	-0.074	0.0	-0.529	0.0	0.024	0.0
274	156.50	0.351	0.0	-0.594	0.0	0.019	0.0
275	157.50	0.710	0.0	-0.564	0.0	0.013	0.0
276	158.50	1.039	0.0	-0.430	0.0	0.009	0.0
277	159.50	[illegible]	0.0	-0.100	0.0	0.005	0.0
278	160.50	1.570	0.0	0.096	0.0	[illegible]	0.0
279	161.50	1.635	0.0	0.297	0.0	-0.026	0.0
280	162.50	1.590	0.0	0.579	0.0	-0.029	0.0
281	163.50	1.127	0.0	0.659	0.0	-0.048	0.0
282	164.50	0.447	0.0	0.602	0.0	[illegible]	0.0
283	165.50	[illegible]	0.0	0.457	0.0	-0.035	0.0
284	166.50	-0.512	0.0	[illegible]	0.0	-0.022	0.0
285	167.50	-0.700	0.0	0.174	0.0	-0.013	0.0
286	168.50	-0.971	0.0	0.005	0.0	[illegible]	0.0
287	169.50	[illegible]	0.0	[illegible]	0.0	[illegible]	0.0
288	170.50	[illegible]	0.0	[illegible]	0.0	-0.005	0.0
289	171.50	[illegible]	0.0	[illegible]	0.0	-0.005	0.0
290	172.50	-1.347	0.0	[illegible]	0.0	0.013	0.0
291	173.50	[illegible]	0.0	[illegible]	0.0	0.032	0.0
292	174.50	[illegible]	0.0	[illegible]	0.0	0.043	0.0
293	175.50	[illegible]	0.0	[illegible]	0.0	[illegible]	0.0
294	176.50	[illegible]	0.0	[illegible]	0.0	[illegible]	0.0
295	177.50	[illegible]	0.0	[illegible]	0.0	0.026	0.0
296	178.50	0.311	0.0	[illegible]	0.0	0.019	0.0
297	179.50	0.712	0.0	[illegible]	0.0	0.015	0.0
298	180.50	[illegible]	0.0	[illegible]	0.0	0.011	0.0
299	181.50	[illegible]	0.0	[illegible]	0.0	0.007	0.0
300	182.50	[illegible]	0.0	[illegible]	0.0	0.002	0.0
301	183.50	1.052	0.0	0.422	0.0	-0.004	0.0
302	184.50	[illegible]	0.0	0.491	0.0	-0.029	0.0
303	185.50	[illegible]	0.0	[illegible]	0.0	-0.057	0.0
304	186.50	0.554	0.0	[illegible]	0.0	-0.059	0.0
305	187.50	[illegible]	0.0	[illegible]	0.0	[illegible]	0.0
306	188.50	[illegible]	0.0	0.353	0.0	-0.022	0.0

STEP	TIME	U DOT	V DOT	W DOT	P DOT	Q DOT	R DOT
409	291.50	0.274	0.0	-0.665	0.0	0.012	0.0
410	292.50	1.235	0.0	-0.449	0.0	0.008	0.0
411	293.50	1.733	0.0	-0.119	0.0	0.004	0.0
412	294.50	1.241	0.0	0.073	0.0	-0.001	0.0
413	295.50	2.017	0.0	0.324	0.0	-0.015	0.0
414	296.50	1.715	0.0	0.703	0.0	-0.050	0.0
415	297.50	[illegible]	0.0	0.707	0.0	-0.062	0.0
416	298.50	1.342	0.0	0.625	0.0	-0.048	0.0
417	299.50	-0.407	0.0	0.420	0.0	-0.029	0.0
418	300.50	-0.772	0.0	0.257	0.0	-0.015	0.0

```
STEP.   TIME      WEIGHT        XG         YC         ZG      BUOYANCY

   1     0.0          0.0      0.0        0.0        0.0          0.0
   2     0.50    139902.3      0.000      0.0        0.000   139910.4
   3     1.00    139874.2      0.000      0.0        0.000   139910.4
   4     1.50    139856.2      0.001      0.0        0.000   139910.4
   5     2.00    139838.1      0.001      0.0        0.000   139910.4
   6     2.50    139821.1      0.001      0.0        0.000   139910.4
   7     3.00    139902.1      0.001      0.0        0.000   139910.4
   8     3.50    140723.9      0.001      0.0        0.000   139910.4
   9     4.00    140764.0      0.001      0.0        0.000   139910.4
  10     4.50    139747.7      0.002      0.0        0.000   139910.4
  11     5.00    139724.7      0.002      0.0        0.000   139910.4
  12     5.50    139711.7      0.002      0.0        0.000   139910.4
  13     6.00    [illegible]   0.002      0.0        0.000   139910.4
  14     6.50    139671.6      0.002      0.0        0.000   139910.4
  15     7.00    [illegible]   0.002      0.0        0.000   139910.4
  16     7.50    [illegible]   0.003      0.0        0.000   139910.4
  17     8.00    [illegible]   0.003      0.0        0.001   139910.4
  18     8.50    [illegible]   0.003      0.0        0.001   139910.4
  19     9.00    139803.2      0.003      0.0        0.001   139910.4
  20     9.50    139767.2      0.003      0.0        0.001   139910.4
  21    10.00    139743.1      0.004      0.0        0.001   139910.4
  22    10.50    139721.1      0.004      0.0        0.001   139910.4
  23    11.00    [illegible]   0.004      0.0        0.001   139910.4
  24    11.50    [illegible]   0.004      0.0        0.001   139910.4
  25    12.00    [illegible]   0.004      0.0        0.001   139910.4
  26    12.50    [illegible]   0.004      0.0        0.001   139910.4
  27    13.00    [illegible]   0.004      0.0        0.001   139910.4
  28    13.50    [illegible]   0.005      0.0        0.001   139910.4
  29    14.00    [illegible]   0.005      0.0        0.001   139910.4
  30    14.50    [illegible]   0.005      0.0        0.001   139910.4
  31    15.00    [illegible]   0.005      0.0        0.001   139910.4
  32    15.50    [illegible]   0.005      0.0        0.001   139910.4
  33    16.00    [illegible]   0.005      0.0        0.001   139910.4
  34    16.50    [illegible]   0.005      0.0        0.001   139910.4
```

```
STEP    TIME     WEIGHT      XG      YG      ZG     BUOYANCY

  35    17.00   139296.2   0.006    0.0    0.001   139910.4
  36    17.50   139278.2   0.006    0.0    0.001   139910.4
  37    18.00   139260.1   0.006    0.0    0.001   139910.4
  38    18.50   139242.1   0.006    0.0    0.001   139910.4
  39    19.00   139224.0   0.007    0.0    0.001   139910.4
  40    19.50   139205.9   0.007    0.0    0.000   139910.4
  41    20.00   139187.9   0.008    0.0    0.000   139910.4
  42    20.50   139169.8   0.008    0.0   -0.000   139910.4
  43    21.00   139151.7   0.009    0.0   -0.001   139910.4
  44    21.50   139133.7   0.009    0.0   -0.001   139910.4
  45    22.00   139115.6   0.009    0.0   -0.001   139910.4
  46    22.50   139097.6   0.010    0.0   -0.002   139910.4
  47    23.00   139079.5   0.010    0.0   -0.002   139910.4
  48    23.50   139061.4   0.011    0.0   -0.003   139910.4
  49    24.00   139043.4   0.011    0.0   -0.003   139910.4
  50    24.50   139025.3   0.012    0.0   -0.003   139910.4
  51    25.00   139007.2   0.012    0.0   -0.004   139910.4
  52    25.50   138989.2   0.012    0.0   -0.004   139910.4
  53    26.00   138971.1   0.013    0.0   -0.005   139910.4
  54    26.50   138953.1   0.013    0.0   -0.005   139910.4
  55    27.00   138935.0   0.014    0.0   -0.005   139910.4
  56    27.50   138916.9   0.014    0.0   -0.006   139910.4
  57    28.00   138898.9   0.015    0.0   -0.006   139910.4
  58    28.50   138880.8   0.015    0.0   -0.007   139910.4
  59    29.00   138862.7   0.015    0.0   -0.007   139910.4
  60    29.50   138844.7   0.016    0.0   -0.007   139910.4
  61    30.00   138826.6   0.016    0.0   -0.008   139910.4
  62    30.50   138808.6   0.017    0.0   -0.008   139910.4
  63    31.00   138790.5   0.017    0.0   -0.009   139910.4
  64    31.50   138772.5   0.018    0.0   -0.009   139910.4
  65    32.00   138754.4   0.018    0.0   -0.009   139910.4
  66    32.50   138736.3   0.018    0.0   -0.010   139910.4
  67    33.00   138718.3   0.019    0.0   -0.010   139910.4
  68    33.50   138700.2   0.019    0.0   -0.010   139910.4
```

```
 STEP     TIME      WEIGHT          XG         YG          ZG       BUOYANCY

  205    102.00    136754.4       0.067       0.0       -0.052     139910.4
  206    102.50    136753.9       0.067       0.0       -0.052     139910.4
  207    103.00    136753.5       0.067       0.0       -0.052     139910.4
  208    103.50    136753.1       0.067       0.0       -0.052     139910.4
  209    104.00    136752.6       0.067       0.0       -0.052     139910.4
  210    104.50    136752.2       0.067       0.0       -0.052     139910.4
  211    105.00    136751.7       0.067       0.0       -0.052     139910.4
  212    105.50    136751.3       0.067       0.0       -0.052     139910.4
  213    106.00    136750.8       0.067       0.0       -0.052     139910.4
  214    106.50    136750.4       0.067       0.0       -0.052     139910.4
  215    107.00    136750.0       0.067       0.0       -0.052     139910.4
  216    107.50    136749.6       0.067       0.0       -0.052     139910.4
  217    108.00    136749.1       0.067       0.0       -0.052     139910.4
  218    108.50    136748.7       0.067       0.0       -0.052     139910.4
  219    109.00    136748.2       0.067       0.0       -0.052     139910.4
  220    109.50    136747.8       0.067       0.0       -0.052     139910.4
  221    110.00    136747.4       0.067       0.0       -0.052     139910.4
  222    110.50    136746.9       0.067       0.0       -0.052     139910.4
  223    111.00    136746.5       0.067       0.0       -0.052     139910.4
  224    111.50    136746.1       0.067       0.0       -0.052     139910.4
  225    112.00    136745.6       0.067       0.0       -0.052     139910.4
  226    112.50    136745.2       0.067       0.0       -0.052     139910.4
  227    113.00    136744.7       0.067       0.0       -0.052     139910.4
  228    113.50    136744.3       0.067       0.0       -0.052     139910.4
  229    114.00    136743.9       0.067       0.0       -0.052     139910.4
  230    114.50    136743.4       0.067       0.0       -0.052     139910.4
  231    115.00    136743.0       0.067       0.0       -0.052     139910.4
  232    115.50    136742.6       0.067       0.0       -0.052     139910.4
  233    116.00    136742.1       0.067       0.0       -0.052     139910.4
  234    116.50    136741.7       0.067       0.0       -0.052     139910.4
  235    117.00    136741.7       0.067       0.0       -0.052     139910.4
  236    117.50    136741.7       0.067       0.0       -0.052     139910.4
  237    118.00    136741.7       0.067       0.0       -0.052     139910.4
  238    118.50    136741.7       0.067       0.0       -0.052     139910.4
```

C - 2 Ascent Trajectory Run

Time increment during deballasting	.1 sec
Time increment after deballasting	.25 sec
Initial roll angle	10.0 deg

All ballast removed

```
STEP   DT      TIME      Y        X        Z        PHI      THETA    PSI

  1   0.0      0.0      0.0      0.0      0.0      0.17     0.0      0.0
  2   0.10     0.10     0.0      0.0     -0.0      0.17     0.00     0.0
  3   0.10     0.20    -0.0      0.0     -0.0      0.17     0.00     0.0
  4   0.10     0.30    -0.0      0.0     -0.0      0.17     0.00     0.0
  5   0.10     0.40    -0.0      0.0     -0.0      0.17     0.00     0.0
  6   0.10     0.50    -0.0      0.0     -0.0      0.17     0.00     0.0
  7   0.10     0.60    -0.0      0.0     -0.0      0.16     0.00     0.0
  8   0.10     0.70    -0.0      0.0     -0.0      0.16     0.00     0.0
  9   0.10     0.80    -0.0      0.0     -0.0      0.16     0.00     0.0
 10   0.10     0.90    -0.0      0.0     -0.0      0.15     0.00     0.0
 11   0.10     1.00    -0.0      0.0     -0.0      0.15     0.00     0.0
 12   0.10     1.10    -0.0      0.0     -0.0      0.14     0.00     0.0
 13   0.10     1.20    -0.0      0.0     -0.0      0.14     0.00     0.0
 14   0.10     1.30    -0.0      0.0     -0.0      0.13     0.00     0.0
 15   0.10     1.40    -0.0      0.0     -0.0      0.12     0.00     0.0
 16   0.10     1.50    -0.0      0.0     -0.0      0.12     0.00     0.0
 17   0.10     1.60    -0.0      0.0     -0.0      0.11     0.00     0.0
 18   0.10     1.70    -0.0      0.0     -0.0      0.10     0.00     0.0
 19   0.10     1.80    -0.0      0.0     -0.0      0.09     0.00     0.0
 20   0.10     1.90    -0.0      0.0     -0.0      0.08     0.00     0.0
 21   0.10     2.00    -0.0      0.0     -0.0      0.08     0.00     0.0
 22   0.10     2.10    -0.0      0.0     -0.0      0.07     0.00     0.0
 23   0.10     2.20    -0.0      0.0     -0.0      0.06     0.00     0.0
 24   0.10     2.30    -0.0      0.0     -0.0      0.05     0.00     0.0
 25   0.10     2.40    -0.0      0.0     -0.0      0.04     0.00     0.0
 26   0.10     2.50    -0.0      0.0     -0.0      0.02     0.00     0.0
 27   0.10     2.60    -0.0      0.0     -0.0      0.02    -0.00     0.0
 28   0.10     2.70    -0.0      0.0     -0.0      0.01    -0.00     0.0
 29   0.10     2.80    -0.0      0.0     -0.0      0.01    -0.00     0.0
 30   0.10     2.90    -0.0      0.0     -0.0     -0.01    -0.00     0.0
 31   0.10     3.00    -0.0      0.0     -0.0     -0.02    -0.00     0.0
 32   0.10     3.10    -0.0      0.0     -0.0     -0.02    -0.00     0.0
 33   0.10     3.20    -0.0      0.0     -0.0     -0.04    -0.00     0.0
 34   0.10     3.30    -0.0      0.0     -0.0     -0.05    -0.00     0.0
```

```
STEP   DT      TIME     X       Y       Z       PHI     THETA    PSI

  35   0.10    3.40    -0.0     0.0    -0.0    -0.06   -0.00     0.00
  36   0.10    3.50    -0.0     0.0    -0.0    -0.07   -0.00     0.00
  37   0.10    3.60    -0.0     0.0    -0.0    -0.08   -0.00     0.00
  38   0.10    3.70    -0.0     0.0    -0.0    -0.08   -0.00     0.00
  39   0.10    3.80    -0.0     0.0    -0.0    -0.09   -0.00     0.00
  40   0.10    3.90    -0.0     0.0    -0.0    -0.10   -0.00     0.00
  41   0.10    4.00    -0.0     0.0    -0.0    -0.11   -0.00     0.00
  42   0.10    4.10    -0.0     0.0    -0.1    -0.12   -0.00     0.00
  43   0.10    4.20    -0.0     0.0    -0.1    -0.13   -0.00     0.00
  44   0.10    4.30    -0.0     0.0    -0.1    -0.13   -0.00     0.00
  45   0.10    4.40    -0.0     0.0    -0.1    -0.14   -0.00     0.00
  46   0.10    4.50    -0.0     0.0    -0.1    -0.15   -0.00     0.00
  47   0.10    4.60    -0.0     0.0    -0.1    -0.15   -0.00     0.00
  48   0.10    4.70    -0.0     0.0    -0.1    -0.16   -0.00     0.00
  49   0.10    4.80    -0.0     0.0    -0.1    -0.16   -0.00     0.00
  50   0.10    4.90    -0.0     0.0    -0.1    -0.17   -0.00     0.00
  51   0.10    5.00    -0.0     0.0    -0.1    -0.17   -0.00     0.00
  52   0.10    5.10    -0.0     0.0    -0.1    -0.17   -0.00     0.00
  53   0.10    5.20    -0.0     0.0    -0.1    -0.18   -0.00     0.00
  54   0.10    5.30    -0.0     0.0    -0.1    -0.18   -0.00     0.00
  55   0.10    5.40    -0.0     0.0    -0.1    -0.18   -0.00     0.00
  56   0.10    5.50    -0.0     0.0    -0.1    -0.19   -0.00     0.00
  57   0.10    5.60    -0.0    -0.0    -0.1    -0.19   -0.00     0.00
  58   0.10    5.70    -0.0    -0.0    -0.1    -0.18   -0.00     0.00
  59   0.10    5.80    -0.0    -0.0    -0.1    -0.18   -0.00     0.00
  60   0.10    5.90    -0.0    -0.0    -0.2    -0.18   -0.00     0.00
  61   0.10    6.00    -0.0    -0.0    -0.2    -0.18   -0.00     0.00
  62   0.10    6.10    -0.0    -0.0    -0.2    -0.18   -0.00     0.00
  63   0.10    6.20    -0.0    -0.0    -0.2    -0.17   -0.00     0.00
  64   0.10    6.30    -0.0    -0.0    -0.2    -0.17   -0.00     0.00
  65   0.10    6.40    -0.0    -0.0    -0.2    -0.17   -0.00     0.00
  66   0.10    6.50    -0.0    -0.0    -0.2    -0.16   -0.00     0.00
  67   0.10    6.60    -0.0    -0.0    -0.2    -0.16   -0.00     0.00
  68   0.10    6.70    -0.0    -0.0    -0.2    -0.15   -0.00     0.00
```

```
STEP   DT        TIME         X          Y          Z        PHI      THETA      PSI

 103  0.10      10.20       -0.0       -0.0       -0.8      0.15     -0.01      0.00
 104  0.10      10.30       -0.0       -0.0       -0.8      0.16     -0.01      0.00
 105  0.10      10.40       -0.0       -0.0       -0.8      0.16     -0.01     -0.00
 106  0.10      10.50       -0.0       -0.0       -0.9      0.17     -0.01     -0.00
 107  0.10      10.60       -0.0       -0.0       -0.9      0.17     -0.01     -0.00
 108  0.10      10.70       -0.0       -0.0       -0.9      0.18     -0.01     -0.00
 109  0.10      10.80       -0.0       -0.0       -0.9      0.18     -0.01     -0.00
 110  0.10      10.90       -0.0       -0.0       -1.0      0.19     -0.01     -0.00
 111  0.10      11.00       -0.0       -0.0       -1.0      0.19     -0.01     -0.00
 112  0.10      11.10       -0.0       -0.0       -1.0      0.19     -0.01     -0.00
 113  0.10      11.20       -0.0        0.0       -1.1      0.19     -0.01     -0.00
 114  0.10      11.30       -0.0        0.0       -1.1      0.19     -0.01     -0.00
 115  0.10      11.40       -0.0        0.0       -1.1      0.19     -0.01     -0.00
 116  0.10      11.50       -0.0        0.0       -1.1      0.19     -0.01     -0.00
 117  0.10      11.60       -0.0        0.0       -1.2      0.19     -0.01     -0.00
 118  0.10      11.70       -0.0        0.0       -1.2      0.18     -0.01     -0.00
 119  0.10      11.80       -0.0        0.0       -1.2      0.18     -0.01     -0.00
 120  0.10      11.90       -0.0        0.0       -1.3      0.18     -0.01     -0.00
 121  0.10      12.00       -0.0        0.0       -1.3      0.18     -0.01     -0.00
 122  0.10      12.10       -0.0        0.0       -1.3      0.17     -0.01     -0.00
 123  0.10      12.20       -0.0        0.0       -1.4      0.17     -0.01     -0.00
 124  0.10      12.30       -0.0        0.0       -1.4      0.16     -0.01     -0.00
 125  0.10      12.40       -0.0        0.0       -1.4      0.16     -0.01     -0.00
 126  0.10      12.50       -0.0        0.0       -1.5      0.15     -0.01     -0.00
 127  0.10      12.60       -0.0        0.0       -1.5      0.14     -0.01     -0.00
 128  0.10      12.70       -0.0        0.0       -1.5      0.14     -0.01     -0.00
 129  0.10      12.80       -0.0        0.0       -1.6      0.13     -0.02     -0.00
 130  0.10      12.90       -0.0        0.0       -1.6      0.12     -0.02     -0.00
 131  0.10      13.00       -0.0        0.0       -1.6      0.11     -0.02      0.00
 132  0.10      13.10       -0.0        0.0       -1.7      0.10     -0.02      0.00
 133  0.10      13.20       -0.0        0.0       -1.7      0.09     -0.02      0.00
 134  0.10      13.30       -0.0        0.0       -1.8      0.09     -0.02      0.00
 135  0.10      13.40       -0.0        0.0       -1.8      0.08     -0.02      0.00
 136  0.10      13.50       -0.0        0.0       -1.9      0.07     -0.02      0.00
```

```
STEP   DT        TIME        X           Y          Z          PHI        THETA      PSI

 171   0.10      17.00      -0.0        0.0       -3.6       -0.19      -0.02       0.00
 172   0.10      17.10      -0.0        0.0       -3.7       -0.19      -0.03       0.00
 173   0.10      17.20      -0.1        0.0       -3.8       -0.19      -0.03       0.00
 174   0.10      17.30      -0.1        0.0       -3.8       -0.19      -0.03       0.00
 175   0.10      17.40      -0.1        0.0       -3.9       -0.19      -0.03       0.00
 176   0.10      17.50      -0.1        0.0       -4.0       -0.19      -0.03       0.00
 177   0.10      17.60      -0.1       -0.0       -4.0       -0.19      -0.03       0.00
 178   0.10      17.70      -0.1       -0.0       -4.1       -0.18      -0.03       0.00
 179   0.10      17.80      -0.1       -0.0       -4.2       -0.17      -0.03       0.00
 180   0.10      17.90      -0.1       -0.0       -4.2       -0.17      -0.03       0.00
 181   0.10      18.00      -0.1       -0.0       -4.3       -0.16      -0.03       0.00
 182   0.10      18.10      -0.1       -0.0       -4.4       -0.16      -0.03       0.00
 183   0.10      18.20      -0.1       -0.0       -4.5       -0.15      -0.04       0.00
 184   0.10      18.30      -0.1       -0.0       -4.5       -0.14      -0.04       0.00
 185   0.10      18.40      -0.1       -0.0       -4.6       -0.14      -0.04       0.00
 186   0.10      18.50      -0.1       -0.0       -4.7       -0.12      -0.04       0.00
 187   0.10      18.60      -0.1       -0.0       -4.7       -0.12      -0.04       0.00
 188   0.10      18.70      -0.1       -0.0       -4.8       -0.11      -0.04       0.00
 189   0.10      18.80      -0.1       -0.0       -4.9       -0.10      -0.04       0.00
 190   0.10      18.90      -0.1       -0.0       -5.0       -0.09      -0.04       0.00
 191   0.10      19.00      -0.1       -0.0       -5.1       -0.08      -0.04       0.00
 192   0.10      19.10      -0.1       -0.0       -5.1       -0.08      -0.04       0.00
 193   0.10      19.20      -0.1       -0.0       -5.2       -0.07      -0.04       0.00
 194   0.10      19.30      -0.1       -0.0       -5.3       -0.06      -0.04       0.00
 195   0.10      19.40      -0.1       -0.0       -5.4       -0.05      -0.04       0.00
 196   0.10      19.50      -0.1       -0.0       -5.5       -0.03      -0.04       0.00
 197   0.10      19.60      -0.1       -0.0       -5.5       -0.02      -0.04       0.00
 198   0.10      19.70      -0.1       -0.0       -5.6       -0.01      -0.04       0.00
 199   0.10      19.80      -0.1       -0.0       -5.7       -0.00      -0.04       0.00
 200   0.10      19.90      -0.1       -0.0       -5.8        0.01      -0.04       0.00
 201   0.10      20.00      -0.1       -0.0       -5.9        0.02      -0.04       0.00
 202   0.10      20.10      -0.1       -0.0       -6.0        0.03      -0.04       0.00
 203   0.10      20.20      -0.1       -0.0       -6.1        0.04      -0.04       0.00
 204   0.10      20.30      -0.1       -0.0       -6.1        0.05      -0.04       0.00
```

```
STEP   DT       TIME        X         Y         Z        PHI      THETA      PSI

 205  0.10     20.40      -0.1      -0.0      -6.2      0.06     -0.04      0.00
 206  0.10     20.50      -0.1      -0.0      -6.3      0.07     -0.05      0.00
 207  0.10     20.60      -0.1      -0.0      -6.4      0.08     -0.05      0.00
 208  0.10     20.70      -0.1      -0.0      -6.5      0.09     -0.05      0.00
 209  0.10     20.80      -0.1      -0.0      -6.6      0.10     -0.05      0.00
 210  0.10     20.90      -0.1      -0.0      -6.7      0.11     -0.05      0.00
 211  0.10     21.00      -0.1      -0.0      -6.8      0.12     -0.05      0.00
 212  0.10     21.10      -0.2      -0.0      -6.9      0.13     -0.05      0.00
 213  0.10     21.20      -0.2      -0.0      -7.0      0.13     -0.05      0.00
 214  0.10     21.30      -0.2      -0.0      -7.1      0.14     -0.05      0.00
 215  0.10     21.40      -0.2      -0.0      -7.2      0.15     -0.05      0.00
 216  0.10     21.50      -0.2      -0.0      -7.3      0.15     -0.05      0.00
 217  0.10     21.60      -0.2      -0.0      -7.4      0.16     -0.05      0.00
 218  0.10     21.70      -0.2      -0.0      -7.5      0.17     -0.05      0.00
 219  0.10     21.80      -0.2      -0.0      -7.6      0.17     -0.05      0.00
 220  0.10     21.90      -0.2      -0.0      -7.7      0.17     -0.05      0.00
 221  0.10     22.00      -0.2      -0.0      -7.8      0.18     -0.05      0.00
 222  0.10     22.10      -0.2      -0.0      -7.9      0.19     -0.05      0.00
 223  0.10     22.20      -0.2      -0.0      -8.0      0.19     -0.05      0.00
 224  0.10     22.30      -0.2      -0.0      -8.1      0.19     -0.05      0.00
 225  0.10     22.40      -0.2      -0.0      -8.2      0.19     -0.05      0.00
 226  0.10     22.50      -0.2      -0.0      -8.3      0.20     -0.05      0.00
 227  0.10     22.60      -0.2      -0.0      -8.4      0.20     -0.05      0.00
 228  0.10     22.70      -0.2      -0.0      -8.5      0.20     -0.06      0.00
 229  0.10     22.80      -0.2      -0.0      -8.6      0.20     -0.06      0.00
 230  0.10     22.90      -0.2      -0.0      -8.7      0.20     -0.06      0.00
 231  0.10     23.00      -0.2      -0.0      -8.8      0.19     -0.06      0.00
 232  0.10     23.10      -0.2      -0.0      -9.0      0.19     -0.06      0.00
 233  0.10     23.20      -0.2      -0.0      -9.1      0.19     -0.06      0.00
 234  0.10     23.30      -0.3      -0.0      -9.2      0.19     -0.06      0.00
 235  0.10     23.40      -0.3      -0.0      -9.3      0.18     -0.06      0.00
 236  0.10     23.50      -0.3      -0.0      -9.4      0.18     -0.06      0.00
 237  0.10     23.60      -0.3       0.0      -9.6      0.18     -0.06      0.00
 238  0.10     23.70      -0.3       0.0      -9.7      0.17     -0.06      0.00
```

STEP	DT	TIME	X	Y	Z	PHI	THETA	PSI
409	0.10	40.90	-3.7	0.4	-45.1	-0.15	-0.11	-0.02
410	0.10	41.00	-3.7	0.4	-45.4	-0.15	-0.11	-0.02
411	0.10	41.10	-3.8	0.4	-45.7	-0.16	-0.11	-0.02
412	0.10	41.20	-3.8	0.4	-46.0	-0.17	-0.11	-0.02
413	0.10	41.30	-3.9	0.4	-46.3	-0.17	-0.11	-0.02
414	0.10	41.40	-3.9	0.4	-46.7	-0.19	-0.11	-0.02
415	0.10	41.50	-3.9	0.4	-47.0	-0.19	-0.11	-0.02
416	0.10	41.60	-4.0	0.4	-47.3	-0.19	-0.11	-0.02
417	0.10	41.70	-4.0	0.4	-47.6	-0.20	-0.11	-0.02
418	0.10	41.80	-4.1	0.4	-47.9	-0.20	-0.11	-0.02
419	0.10	41.90	-4.1	0.4	-48.2	-0.21	-0.11	-0.02
420	0.10	42.00	-4.1	0.4	-48.5	-0.21	-0.11	-0.02
421	0.10	42.10	-4.2	0.4	-48.8	-0.21	-0.11	-0.02
422	0.10	42.20	-4.2	0.4	-49.1	-0.22	-0.11	-0.02
423	0.10	42.30	-4.2	0.4	-49.5	-0.22	-0.11	-0.02
424	0.10	42.40	-4.3	0.4	-49.8	-0.22	-0.11	-0.02
425	0.10	42.50	-4.3	0.4	-50.1	-0.23	-0.11	-0.02
426	0.10	42.60	-4.4	0.3	-50.4	-0.23	-0.11	-0.02
427	0.10	42.70	-4.4	0.3	-50.7	-0.23	-0.11	-0.02
428	0.10	42.80	-4.5	0.3	-51.0	-0.24	-0.11	-0.02
429	0.10	42.90	-4.5	0.3	-51.4	-0.24	-0.11	-0.02
430	0.10	43.00	-4.5	0.3	-51.7	-0.24	-0.11	-0.02
431	0.10	43.10	-4.6	0.3	-52.0	-0.24	-0.11	-0.02
432	0.10	43.20	-4.6	0.3	-52.3	-0.24	-0.11	-0.02
433	0.10	43.30	-4.7	0.3	-52.7	-0.24	-0.11	-0.02
434	0.10	43.40	-4.7	0.2	-53.0	-0.24	-0.11	-0.01
435	0.10	43.50	-4.7	0.2	-53.3	-0.24	-0.11	-0.01
436	0.10	43.60	-4.8	0.2	-53.6	-0.24	-0.11	-0.01
437	0.10	43.70	-4.8	0.2	-54.0	-0.24	-0.11	-0.01
438	0.10	43.80	-4.9	0.2	-54.3	-0.24	-0.11	-0.01
439	0.10	43.90	-4.9	0.2	-54.6	-0.24	-0.11	-0.01
440	0.10	44.00	-4.9	0.1	-55.0	-0.24	-0.11	-0.01
441	0.10	44.10	-5.0	0.1	-55.3	-0.24	-0.11	-0.01
442	0.10	44.20	-5.0	0.1	-55.6	-0.24	-0.11	-0.01

STEP	DT	TIME	X	Y	Z	PHI	THETA	PSI
443	0.10	44.20	-5.1	0.1	-56.0	-0.23	-0.11	-0.01
444	0.10	44.30	-5.1	0.0	-56.3	-0.22	-0.11	-0.00
445	0.10	44.40	-5.1	0.0	-56.6	-0.23	-0.11	-0.00
446	0.10	44.50	-5.2	0.0	-57.0	-0.23	-0.11	0.00
447	0.10	44.60	-5.2	-0.0	-57.3	-0.22	-0.11	0.00
448	0.10	44.70	-5.2	-0.0	-57.7	-0.22	-0.11	0.00
449	0.10	44.80	-5.3	-0.1	-58.0	-0.21	-0.11	0.01
450	0.10	44.90	-5.3	-0.1	-58.3	-0.21	-0.11	0.01
451	0.10	45.00	-5.4	-0.1	-58.7	-0.21	-0.11	0.01
452	0.10	45.10	-5.4	-0.2	-59.0	-0.20	-0.11	0.01
453	0.10	45.20	-5.4	-0.2	-59.4	-0.20	-0.11	0.01
454	0.10	45.30	-5.5	-0.2	-59.7	-0.19	-0.11	0.01
455	0.10	45.40	-5.5	-0.2	-60.1	-0.19	-0.11	0.02
456	0.10	45.50	-5.6	-0.3	-60.4	-0.18	-0.11	0.02
457	0.10	45.60	-5.6	-0.3	-60.8	-0.18	-0.11	0.02
458	0.10	45.70	-5.6	-0.3	-61.1	-0.17	-0.11	0.02
459	0.10	45.80	-5.7	-0.3	-61.5	-0.16	-0.11	0.02
460	0.10	45.90	-5.7	-0.4	-61.8	-0.16	-0.11	0.02
461	0.10	46.00	-5.8	-0.4	-62.2	-0.15	-0.11	0.03
462	0.10	46.10	-5.8	-0.4	-62.5	-0.15	-0.11	0.03
463	0.10	46.20	-5.9	-0.5	-62.9	-0.14	-0.10	0.03
464	0.10	46.30	-5.9	-0.5	-63.2	-0.13	-0.10	0.03
465	0.10	46.40	-5.9	-0.5	-63.6	-0.13	-0.10	0.03
466	0.10	46.50	-5.9	-0.6	-64.0	-0.12	-0.10	0.04
467	0.10	46.60	-6.0	-0.6	-64.3	-0.11	-0.10	0.04
468	0.10	46.70	-6.0	-0.6	-64.7	-0.10	-0.10	0.04
469	0.10	46.80	-6.0	-0.6	-65.0	-0.10	-0.11	0.04
470	0.10	46.90	-6.1	-0.7	-65.4	-0.09	-0.10	0.04
471	0.10	47.00	-6.1	-0.7	-65.8	-0.08	-0.11	0.05
472	0.10	47.10	-6.2	-0.7	-66.1	-0.07	-0.10	0.05
473	0.10	47.20	-6.2	-0.8	-66.5	-0.06	-0.10	0.05
474	0.10	47.30	-6.2	-0.8	-66.9	-0.06	-0.11	0.05
475	0.10	47.40	-6.3	-0.8	-67.2	-0.05	-0.10	0.05
476	0.10	47.50	-6.3	-0.8	-67.6	-0.04	-0.10	0.06

```
STEP    TIME      U          V          W          P          Q          R
                 BODY       BODY       BODY       BODY       BODY       BODY

  1     0.0      0.0        0.0        0.0        0.0        0.0        0.0
  2     0.10     0.0        0.000     -0.000     -0.005     -0.000      0.000
  3     0.20    -0.000      0.000     -0.000     -0.011     -0.000      0.000
  4     0.30     0.000      0.000     -0.000     -0.016     -0.000      0.000
  5     0.40     0.000     -0.000     -0.000     -0.021     -0.000      0.000
  6     0.50    -0.000     -0.000     -0.001     -0.026     -0.000      0.000
  7     0.60    -0.000     -0.000     -0.001     -0.032     -0.000      0.000
  8     0.70    -0.000     -0.000     -0.001     -0.037     -0.000      0.001
  9     0.80    -0.000     -0.000     -0.002     -0.042     -0.000      0.001
 10     0.90    -0.000     -0.000     -0.002     -0.046     -0.000      0.001
 11     1.00    -0.000     -0.000     -0.002     -0.051     -0.000      0.001
 12     1.10    -0.000     -0.000     -0.003     -0.056     -0.000      0.001
 13     1.20    -0.000     -0.000     -0.003     -0.061     -0.000      0.001
 14     1.30    -0.000     -0.000     -0.004     -0.064     -0.000      0.001
 15     1.40    -0.000     -0.000     -0.005     -0.069     -0.000      0.001
 16     1.50    -0.000     -0.000     -0.005     -0.072     -0.000      0.001
 17     1.60    -0.000     -0.000     -0.006     -0.076     -0.000      0.001
 18     1.70    -0.000     -0.000     -0.007     -0.079     -0.000      0.001
 19     1.80    -0.000     -0.000     -0.008     -0.082     -0.000      0.001
 20     1.90    -0.000     -0.000     -0.009     -0.085     -0.000      0.001
 21     2.00    -0.000     -0.000     -0.009     -0.087     -0.000      0.001
 22     2.10    -0.000     -0.000     -0.010     -0.090     -0.000      0.001
 23     2.20    -0.000     -0.000     -0.011     -0.092     -0.000      0.001
 24     2.30    -0.000     -0.000     -0.012     -0.094     -0.000      0.001
 25     2.40    -0.000     -0.000     -0.013     -0.096     -0.000      0.001
 26     2.50    -0.000     -0.000     -0.014     -0.097     -0.000      0.001
 27     2.60    -0.000     -0.000     -0.016     -0.098     -0.000      0.001
 28     2.70    -0.000     -0.000     -0.017     -0.099     -0.000      0.001
 29     2.80    -0.000      0.000     -0.018     -0.099     -0.000      0.001
 30     2.90    -0.000      0.000     -0.019     -0.100     -0.000      0.001
 31     3.00    -0.000      0.000     -0.021     -0.099     -0.000      0.001
 32     3.10    -0.000      0.001     -0.022     -0.098     -0.000      0.001
 33     3.20    -0.000      0.001     -0.023     -0.097     -0.000      0.001
 34     3.30    -0.000      0.001     -0.025     -0.096     -0.000      0.001
```

103-H

```
STEP    TIME       U          V          W          P          Q          R
                  BODY       BODY       BODY       BODY       BODY       BODY

  35    3.40     -0.000      0.001     -0.026     -0.094     -0.000      0.001
  36    3.50     -0.000      0.002     -0.028     -0.093     -0.000      0.001
  37    3.60     -0.000      0.002     -0.030     -0.091     -0.001      0.001
  38    3.70     -0.000      0.002     -0.031     -0.088     -0.000      0.001
  39    3.80     -0.000      0.003     -0.033     -0.086     -0.000      0.001
  40    3.90     -0.000      0.003     -0.035     -0.083     -0.001      0.001
  41    4.00     -0.000      0.004     -0.036     -0.080     -0.001      0.001
  42    4.10     -0.000      0.004     -0.038     -0.076     -0.001      0.001
  43    4.20     -0.000      0.005     -0.041     -0.073     -0.001      0.001
  44    4.30     -0.000      0.005     -0.042     -0.069     -0.001      0.001
  45    4.40     -0.000      0.006     -0.044     -0.065     -0.001      0.001
  46    4.50     -0.000      0.006     -0.046     -0.061     -0.001      0.001
  47    4.60     -0.000      0.007     -0.048     -0.056     -0.001      0.001
  48    4.70     -0.000      0.007     -0.050     -0.051     -0.001      0.001
  49    4.80     -0.000      0.008     -0.052     -0.046     -0.001      0.000
  50    4.90     -0.000      0.009     -0.054     -0.041     -0.001      0.000
  51    5.00     -0.000      0.010     -0.056     -0.036     -0.001      0.000
  52    5.10     -0.000      0.010     -0.058     -0.031     -0.001      0.000
  53    5.20     -0.000      0.011     -0.060     -0.026     -0.001      0.000
  54    5.30     -0.000      0.011     -0.063     -0.020     -0.001      0.000
  55    5.40     -0.000      0.011     -0.065     -0.015     -0.001      0.000
  56    5.50     -0.000      0.011     -0.067     -0.009     -0.001      0.000
  57    5.60     -0.000      0.012     -0.070     -0.004     -0.001     -0.000
  58    5.70     -0.000      0.012     -0.072      0.002     -0.001     -0.000
  59    5.80     -0.000      0.013     -0.075      0.007     -0.001     -0.000
  60    5.90     -0.000      0.013     -0.078      0.013     -0.001     -0.000
  61    6.00     -0.000      0.013     -0.080      0.019     -0.001     -0.000
  62    6.10     -0.000      0.014     -0.083      0.024     -0.001     -0.000
  63    6.20     -0.000      0.014     -0.086      0.030     -0.001     -0.000
  64    6.30     -0.000      0.014     -0.088      0.035     -0.001     -0.001
  65    6.40     -0.000      0.014     -0.091      0.040     -0.001     -0.001
  66    6.50     -0.000      0.014     -0.094      0.045     -0.001     -0.001
  67    6.60     -0.000      0.014     -0.097      0.051     -0.001     -0.001
  68    6.70     -0.000      0.014     -0.100      0.055     -0.001     -0.001
```

STEP	TIME	U BODY	V BODY	W BODY	P BODY	Q BODY	R BODY
103	10.20	-0.003	-0.032	-0.231	0.061	-0.002	-0.001
104	10.30	-0.004	-0.033	-0.235	0.056	-0.002	-0.001
105	10.40	-0.004	-0.035	-0.239	0.051	-0.002	-0.000
106	10.50	-0.004	-0.037	-0.244	0.046	-0.002	-0.000
107	10.60	-0.004	-0.039	-0.248	0.041	-0.002	-0.000
108	10.70	-0.004	-0.040	-0.253	0.035	-0.002	-0.000
109	10.80	-0.004	-0.042	-0.257	0.030	-0.002	-0.000
110	10.90	-0.005	-0.043	-0.262	0.024	-0.002	-0.000
111	11.00	-0.005	-0.045	-0.266	0.019	-0.003	0.000
112	11.10	-0.005	-0.046	-0.271	0.013	-0.003	0.000
113	11.20	-0.005	-0.047	-0.276	0.007	-0.003	0.000
114	11.30	-0.005	-0.048	-0.281	0.001	-0.003	0.000
115	11.40	-0.006	-0.049	-0.286	-0.004	-0.003	0.000
116	11.50	-0.006	-0.050	-0.291	-0.010	-0.003	0.000
117	11.60	-0.006	-0.051	-0.296	-0.016	-0.003	0.000
118	11.70	-0.006	-0.051	-0.301	-0.022	-0.003	0.001
119	11.80	-0.007	-0.051	-0.306	-0.027	-0.003	0.001
120	11.90	-0.007	-0.051	-0.311	-0.033	-0.003	0.001
121	12.00	-0.007	-0.051	-0.317	-0.038	-0.003	0.001
122	12.10	-0.008	-0.050	-0.322	-0.044	-0.003	0.001
123	12.20	-0.008	-0.050	-0.327	-0.049	-0.003	0.001
124	12.30	-0.009	-0.049	-0.332	-0.054	-0.003	0.001
125	12.40	-0.009	-0.048	-0.338	-0.059	-0.003	0.001
126	12.50	-0.009	-0.047	-0.344	-0.064	-0.003	0.001
127	12.60	-0.009	-0.046	-0.350	-0.068	-0.003	0.001
128	12.70	-0.010	-0.044	-0.356	-0.073	-0.003	0.001
129	12.80	-0.010	-0.043	-0.362	-0.077	-0.003	0.001
130	12.90	-0.010	-0.041	-0.368	-0.081	-0.003	0.001
131	13.00	-0.011	-0.039	-0.374	-0.085	-0.003	0.001
132	13.10	-0.011	-0.036	-0.380	-0.088	-0.003	0.001
133	13.20	-0.011	-0.034	-0.386	-0.091	-0.003	0.001
134	13.30	-0.012	-0.031	-0.392	-0.094	-0.003	0.001
135	13.40	-0.012	-0.029	-0.398	-0.097	-0.003	0.001
136	13.50	-0.012	-0.025	-0.404	-0.099	-0.003	0.001

STEP	TIME	U BODY	V BODY	W BODY	P BODY	Q BODY	R BODY
171	17.00	-0.034	0.109	-0.623	0.001	-0.004	-0.000
172	17.10	-0.035	0.110	-0.630	0.007	-0.004	-0.000
173	17.20	-0.036	0.111	-0.637	0.013	-0.004	-0.001
174	17.30	-0.037	0.111	-0.644	0.018	-0.004	-0.001
175	17.40	-0.038	0.111	-0.652	0.024	-0.004	-0.001
176	17.50	-0.039	0.111	-0.659	0.030	-0.004	-0.001
177	17.60	-0.039	0.110	-0.667	0.035	-0.004	-0.001
178	17.70	-0.040	0.109	-0.675	0.041	-0.004	-0.001
179	17.80	-0.041	0.107	-0.683	0.046	-0.004	-0.001
180	17.90	-0.042	0.105	-0.691	0.052	-0.004	-0.001
181	18.00	-0.043	0.103	-0.699	0.057	-0.004	-0.001
182	18.10	-0.044	0.100	-0.707	0.062	-0.004	-0.001
183	18.20	-0.046	0.097	-0.715	0.066	-0.004	-0.001
184	18.30	-0.047	0.094	-0.723	0.071	-0.004	-0.001
185	18.40	-0.049	0.090	-0.731	0.075	-0.004	-0.001
186	18.50	-0.049	0.085	-0.740	0.079	-0.004	-0.001
187	18.60	-0.050	0.081	-0.748	0.083	-0.004	-0.001
188	18.70	-0.051	0.076	-0.757	0.087	-0.004	-0.001
189	18.80	-0.052	0.070	-0.765	0.091	-0.004	-0.001
190	18.90	-0.053	0.065	-0.774	0.093	-0.004	-0.001
191	19.00	-0.055	0.059	-0.782	0.096	-0.004	-0.001
192	19.10	-0.056	0.052	-0.791	0.098	-0.004	-0.001
193	19.20	-0.057	0.045	-0.799	0.100	-0.004	-0.001
194	19.30	-0.058	0.038	-0.807	0.102	-0.004	-0.001
195	19.40	-0.059	0.031	-0.816	0.104	-0.004	-0.001
196	19.50	-0.061	0.024	-0.824	0.105	-0.004	-0.001
197	19.60	-0.062	0.016	-0.832	0.106	-0.004	-0.001
198	19.70	-0.063	0.008	-0.841	0.106	-0.004	-0.001
199	19.80	-0.065	-0.000	-0.849	0.107	-0.004	-0.001
200	19.90	-0.066	-0.009	-0.857	0.107	-0.004	-0.001
201	20.00	-0.067	-0.017	-0.865	0.106	-0.004	-0.001
202	20.10	-0.069	-0.026	-0.873	0.106	-0.005	-0.001
203	20.20	-0.071	-0.034	-0.881	0.105	-0.005	-0.001
204	20.30	-0.071	-0.042	-0.890	0.105	-0.005	-0.001

103-K

STEP	TIME	U BODY	V BODY	W BODY	P BODY	Q BODY	R BODY
205	20.40	-0.073	-0.051	-0.896	0.102	-0.005	-0.001
206	20.50	-0.074	-0.060	-0.904	0.100	-0.005	-0.001
207	20.60	-0.076	-0.069	-0.912	0.097	-0.005	-0.001
208	20.70	-0.077	-0.077	-0.919	0.095	-0.005	-0.001
209	20.80	-0.079	-0.086	-0.927	0.092	-0.005	-0.001
210	20.90	-0.080	-0.094	-0.934	0.089	-0.005	-0.001
211	21.00	-0.082	-0.102	-0.942	0.086	-0.005	-0.000
212	21.10	-0.083	-0.110	-0.949	0.082	-0.005	-0.000
213	21.20	-0.085	-0.118	-0.957	0.078	-0.005	-0.000
214	21.30	-0.086	-0.125	-0.964	0.074	-0.005	-0.000
215	21.40	-0.088	-0.133	-0.972	0.070	-0.005	-0.000
216	21.50	-0.090	-0.139	-0.979	0.066	-0.005	-0.000
217	21.60	-0.091	-0.146	-0.987	0.061	-0.005	-0.000
218	21.70	-0.093	-0.152	-0.994	0.056	-0.005	-0.000
219	21.80	-0.095	-0.158	-1.002	0.051	-0.005	-0.000
220	21.90	-0.096	-0.164	-1.010	0.046	-0.005	-0.000
221	22.00	-0.098	-0.169	-1.017	0.041	-0.005	0.000
222	22.10	-0.100	-0.174	-1.025	0.036	-0.005	0.000
223	22.20	-0.102	-0.178	-1.033	0.030	-0.005	0.000
224	22.30	-0.103	-0.182	-1.041	0.025	-0.005	0.000
225	22.40	-0.105	-0.185	-1.050	0.019	-0.005	0.000
226	22.50	-0.107	-0.187	-1.058	0.013	-0.005	0.000
227	22.60	-0.109	-0.190	-1.066	0.008	-0.005	0.000
228	22.70	-0.111	-0.191	-1.075	0.002	-0.005	0.000
229	22.80	-0.113	-0.192	-1.084	-0.004	-0.005	0.000
230	22.90	-0.114	-0.193	-1.093	-0.009	-0.005	0.000
231	23.00	-0.116	-0.193	-1.102	-0.015	-0.005	0.000
232	23.10	-0.118	-0.192	-1.111	-0.020	-0.005	0.000
233	23.20	-0.120	-0.191	-1.121	-0.026	-0.005	0.000
234	23.30	-0.122	-0.189	-1.130	-0.031	-0.005	0.000
235	23.40	-0.124	-0.187	-1.140	-0.036	-0.005	0.000
236	23.50	-0.127	-0.184	-1.149	-0.042	-0.005	0.000
237	23.60	-0.129	-0.180	-1.159	-0.047	-0.005	0.000
238	23.70	-0.131	-0.176	-1.169	-0.052	-0.005	0.000

STEP	TIME	U BODY	V BODY	W BODY	P BODY	Q BODY	R BODY
409	40.80	-0.708	0.433	-2.921	-0.071	0.003	-0.002
410	40.90	-0.710	0.449	-2.929	-0.068	0.003	-0.002
411	41.00	-0.712	0.464	-2.937	-0.066	0.003	-0.001
412	41.10	-0.714	0.478	-2.945	-0.063	0.003	-0.001
413	41.20	-0.716	0.492	-2.953	-0.061	0.003	-0.000
414	41.30	-0.718	0.505	-2.961	-0.059	0.003	-0.000
415	41.40	-0.720	0.517	-2.969	-0.056	0.003	0.000
416	41.50	-0.722	0.529	-2.978	-0.054	0.003	0.001
417	41.60	-0.724	0.540	-2.986	-0.051	0.003	0.001
418	41.70	-0.726	0.550	-2.994	-0.048	0.003	0.002
419	41.80	-0.727	0.560	-3.003	-0.045	0.003	0.002
420	41.90	-0.729	0.568	-3.012	-0.042	0.003	0.003
421	42.00	-0.730	0.576	-3.020	-0.040	0.003	0.003
422	42.10	-0.732	0.584	-3.029	-0.037	0.003	0.004
423	42.20	-0.733	0.590	-3.038	-0.034	0.003	0.004
424	42.30	-0.734	0.596	-3.048	-0.031	0.003	0.005
425	42.40	-0.736	0.601	-3.057	-0.028	0.003	0.005
426	42.50	-0.737	0.605	-3.067	-0.025	0.003	0.006
427	42.60	-0.738	0.608	-3.076	-0.022	0.003	0.007
428	42.70	-0.739	0.610	-3.086	-0.019	0.003	0.007
429	42.80	-0.740	0.612	-3.096	-0.016	0.003	0.008
430	42.90	-0.741	0.613	-3.107	-0.013	0.003	0.008
431	43.00	-0.742	0.613	-3.117	-0.010	0.003	0.009
432	43.10	-0.742	0.612	-3.128	-0.007	0.003	0.009
433	43.20	-0.743	0.611	-3.139	-0.004	0.003	0.010
434	43.30	-0.744	0.608	-3.150	-0.001	0.003	0.010
435	43.40	-0.745	0.605	-3.161	0.002	0.003	0.011
436	43.50	-0.745	0.601	-3.172	0.005	0.003	0.011
437	43.60	-0.746	0.596	-3.184	0.008	0.003	0.012
438	43.70	-0.746	0.590	-3.195	0.010	0.003	0.012
439	43.80	-0.747	0.584	-3.207	0.013	0.003	0.013
440	43.90	-0.747	0.577	-3.219	0.016	0.003	0.013
441	44.00	-0.748	0.569	-3.231	0.019	0.003	0.014
442	44.10	-0.748	0.560	-3.243	0.022	0.003	0.014

STEP	TIME	U BODY	V BODY	W BODY	P BODY	Q BODY	R BODY
443	44.20	-0.748	0.550	-3.256	0.025	0.003	0.015
444	44.30	-0.749	0.540	-3.268	0.027	0.003	0.015
445	44.40	-0.749	0.529	-3.280	0.030	0.003	0.015
446	44.50	-0.749	0.517	-3.293	0.033	0.003	0.016
447	44.60	-0.750	0.505	-3.306	0.035	0.003	0.016
448	44.70	-0.750	0.492	-3.318	0.038	0.003	0.017
449	44.80	-0.750	0.478	-3.331	0.041	0.003	0.017
450	44.90	-0.750	0.464	-3.344	0.043	0.003	0.017
451	45.00	-0.751	0.448	-3.357	0.045	0.004	0.018
452	45.10	-0.751	0.433	-3.370	0.048	0.004	0.018
453	45.20	-0.751	0.416	-3.382	0.050	0.004	0.018
454	45.30	-0.751	0.399	-3.395	0.052	0.004	0.019
455	45.40	-0.751	0.382	-3.408	0.054	0.004	0.019
456	45.50	-0.752	0.363	-3.420	0.056	0.004	0.019
457	45.60	-0.752	0.345	-3.433	0.059	0.004	0.019
458	45.70	-0.752	0.325	-3.446	0.061	0.004	0.020
459	45.80	-0.752	0.306	-3.458	0.063	0.005	0.020
460	45.90	-0.752	0.285	-3.470	0.064	0.005	0.020
461	46.00	-0.752	0.265	-3.483	0.066	0.005	0.020
462	46.10	-0.752	0.243	-3.495	0.068	0.005	0.021
463	46.20	-0.752	0.222	-3.507	0.070	0.005	0.020
464	46.30	-0.753	0.200	-3.519	0.071	0.005	0.020
465	46.40	-0.753	0.177	-3.530	0.073	0.005	0.020
466	46.50	-0.753	0.154	-3.542	0.075	0.006	0.020
467	46.60	-0.753	0.131	-3.553	0.076	0.006	0.020
468	46.70	-0.753	0.107	-3.564	0.077	0.006	0.020
469	46.80	-0.753	0.084	-3.575	0.079	0.006	0.020
470	46.90	-0.753	0.059	-3.586	0.080	0.006	0.020
471	47.00	-0.753	0.035	-3.596	0.081	0.006	0.020
472	47.10	-0.753	0.010	-3.606	0.082	0.007	0.020
473	47.20	-0.752	-0.015	-3.616	0.084	0.007	0.020
474	47.30	-0.752	-0.040	-3.626	0.085	0.007	0.020
475	47.40	-0.752	-0.065	-3.636	0.086	0.007	0.019
476	47.50	-0.752	-0.091	-3.645	0.087	0.007	0.019

```
STEP    TIME      WEIGHT        XG        YG        ZG     BUOYANCY

   1    0.0          0.0      0.0       0.0       0.0          0.0
   2    0.10    139906.7      0.000     0.0       0.000   139910.4
   3    0.20    139903.1      0.000     0.0       0.000   139910.4
   4    0.30    139899.5      0.000     0.0       0.000   139910.4
   5    0.40    139895.9      0.000     0.0       0.000   139910.4
   6    0.50    139892.2      0.000     0.0       0.000   139910.4
   7    0.60    139888.6      0.000     0.0       0.000   139910.4
   8    0.70    139885.0      0.000     0.0       0.000   139910.4
   9    0.80    139881.4      0.000     0.0       0.000   139910.4
  10    0.90    139877.7      0.000     0.0       0.000   139910.4
  11    1.00    139874.1      0.000     0.0       0.000   139910.4
  12    1.10    139870.5      0.000     0.0       0.000   139910.4
  13    1.20    139866.9      0.000     0.0       0.000   139910.4
  14    1.30    139863.2      0.000     0.0       0.000   139910.4
  15    1.40    139859.6      0.000     0.0       0.000   139910.4
  16    1.50    139856.0      0.001     0.0       0.000   139910.4
  17    1.60    139852.4      0.001     0.0       0.000   139910.4
  18    1.70    139848.7      0.001     0.0       0.000   139910.4
  19    1.80    139845.1      0.001     0.0       0.000   139910.4
  20    1.90    139841.5      0.001     0.0       0.000   139910.4
  21    2.00    139837.9      0.001     0.0       0.000   139910.4
  22    2.10    139834.2      0.001     0.0       0.000   139910.4
  23    2.20    139830.6      0.001     0.0       0.000   139910.4
  24    2.30    139827.0      0.001     0.0       0.000   139910.4
  25    2.40    139823.4      0.001     0.0       0.000   139910.4
  26    2.50    139819.7      0.001     0.0       0.000   139910.4
  27    2.60    139816.1      0.001     0.0       0.000   139910.4
  28    2.70    139812.5      0.001     0.0       0.000   139910.4
  29    2.80    139808.9      0.001     0.0       0.000   139910.4
  30    2.90    139805.2      0.001     0.0       0.000   139910.4
  31    3.00    139801.6      0.001     0.0       0.000   139910.4
  32    3.10    139798.0      0.001     0.0       0.000   139910.4
  33    3.20    139794.4      0.001     0.0       0.000   139910.4
  34    3.30    139790.7      0.001     0.0       0.000   139910.4
```

STEP	TIME	WEIGHT	XG	YG	ZG	BUOYANCY
375	37.40	138554.6	0.023	0.0	-0.013	139910.4
376	37.50	138551.0	0.023	0.0	-0.013	139910.4
377	37.60	138547.4	0.023	0.0	-0.013	139910.4
378	37.70	138543.7	0.023	0.0	-0.013	139910.4
379	37.80	138540.1	0.023	0.0	-0.013	139910.4
380	37.90	138536.5	0.023	0.0	-0.013	139910.4
381	38.00	138532.9	0.023	0.0	-0.013	139910.4
382	38.10	138529.2	0.023	0.0	-0.014	139910.4
383	38.20	138525.6	0.023	0.0	-0.014	139910.4
384	38.30	138522.0	0.023	0.0	-0.014	139910.4
385	38.40	138518.4	0.023	0.0	-0.014	139910.4
386	38.50	138514.7	0.024	0.0	-0.014	139910.4
387	38.60	138511.1	0.024	0.0	-0.014	139910.4
388	38.70	138507.5	0.024	0.0	-0.014	139910.4
389	38.80	138503.9	0.024	0.0	-0.014	139910.4
390	38.90	138500.2	0.024	0.0	-0.014	139910.4
391	39.00	138496.6	0.024	0.0	-0.014	139910.4
392	39.10	138493.0	0.024	0.0	-0.014	139910.4
393	39.20	138489.4	0.024	0.0	-0.014	139910.4
394	39.30	138485.7	0.024	0.0	-0.014	139910.4
395	39.40	138482.1	0.024	0.0	-0.015	139910.4
396	39.50	138478.5	0.024	0.0	-0.015	139910.4
397	39.60	138474.9	0.025	0.0	-0.015	139910.4
398	39.70	138471.2	0.025	0.0	-0.015	139910.4
399	39.80	138467.6	0.025	0.0	-0.015	139910.4
400	39.90	138464.0	0.025	0.0	-0.015	139910.4
401	40.00	138460.4	0.025	0.0	-0.015	139910.4
402	40.10	138456.7	0.025	0.0	-0.015	139910.4
403	40.20	138453.1	0.025	0.0	-0.015	139910.4
404	40.30	138449.5	0.025	0.0	-0.015	139910.4
405	40.40	138445.9	0.025	0.0	-0.015	139910.4
406	40.50	138442.2	0.025	0.0	-0.015	139910.4
407	40.60	138438.6	0.025	0.0	-0.015	139910.4
408	40.70	138435.0	0.025	0.0	-0.016	139910.4

```
STEP    TIME     WEIGHT       XG       YG        ZG     BUOYANCY

 443    44.20   138308.1    0.029     0.0    -0.018   139910.4
 444    44.30   138304.5    0.029     0.0    -0.018   139910.4
 445    44.40   138300.9    0.029     0.0    -0.018   139910.4
 446    44.50   138297.2    0.029     0.0    -0.019   139910.4
 447    44.60   138293.6    0.029     0.0    -0.019   139910.4
 448    44.70   138290.0    0.029     0.0    -0.019   139910.4
 449    44.80   138286.4    0.029     0.0    -0.019   139910.4
 450    44.90   138282.7    0.029     0.0    -0.019   139910.4
 451    45.00   138279.1    0.029     0.0    -0.019   139910.4
 452    45.10   138275.5    0.029     0.0    -0.019   139910.4
 453    45.20   138271.9    0.029     0.0    -0.019   139910.4
 454    45.30   138268.2    0.030     0.0    -0.019   139910.4
 455    45.40   138264.6    0.030     0.0    -0.019   139910.4
 456    45.50   138261.0    0.030     0.0    -0.019   139910.4
 457    45.60   138257.4    0.030     0.0    -0.019   139910.4
 458    45.70   138253.7    0.031     0.0    -0.019   139910.4
 459    45.80   138250.1    0.030     0.0    -0.020   139910.4
 460    45.90   138246.5    0.030     0.0    -0.020   139910.4
 461    46.00   138242.9    0.030     0.0    -0.020   139910.4
 462    46.10   138239.2    0.030     0.0    -0.020   139910.4
 463    46.20   138235.6    0.030     0.0    -0.020   139910.4
 464    46.30   138232.0    0.030     0.0    -0.020   139910.4
 465    46.40   138228.4    0.030     0.0    -0.020   139910.4
 466    46.50   138224.7    0.031     0.0    -0.020   139910.4
 467    46.60   138221.1    0.031     0.0    -0.020   139910.4
 468    46.70   138217.5    0.031     0.0    -0.020   139910.4
 469    46.80   138213.9    0.031     0.0    -0.020   139910.4
 470    46.90   138210.2    0.031     0.0    -0.020   139910.4
 471    47.00   138206.6    0.031     0.0    -0.020   139910.4
 472    47.10   138203.0    0.031     0.0    -0.021   139910.4
 473    47.20   138199.4    0.031     0.0    -0.021   139910.4
 474    47.30   138195.7    0.031     0.0    -0.021   139910.4
 475    47.40   138192.1    0.031     0.0    -0.021   139910.4
 476    47.50   138188.5    0.031     0.0    -0.021   139910.4
```

C - 3 Attempt for problem Three

Failed due to excessive time increment

Time increment during deballasting	1.0 sec
Time increment after deballasting	2.0 sec
Initial roll angle	10.0 deg

All ballast removed

STEP	DT	TIME	X	Y	Z	PHI	THETA	PSI
1	0.0	0.0	0.0	0.0	0.0	0.17	[illegible]	[illegible]
2	1.00	1.00	0.0	0.0	-0.0	0.15	0.[illegible]	[illegible]
3	1.00	2.00	-0.0	0.0	-0.0	0.07	[illegible]	[illegible]
4	1.00	3.00	-0.0	0.0	-0.0	-0.04	[illegible]	[illegible]
5	1.00	4.00	-0.0	0.0	-0.1	-0.10	[illegible]	[illegible]
6	1.00	5.00	-0.0	0.0	-0.1	-0.24	[illegible]	[illegible]
7	1.00	6.00	-0.0	0.0	-0.2	-0.25	[illegible]	[illegible]
8	1.00	7.00	-0.0	-0.0	-0.3	-0.21	[illegible]	[illegible]
9	1.00	8.00	-0.0	-0.0	-0.5	-0.03	[illegible]	[illegible]
10	1.00	9.00	-0.0	-0.0	-0.6	0.03	[illegible]	[illegible]
11	1.00	10.00	-0.0	-0.0	-0.9	0.25	-0.01	[illegible]
12	1.00	11.00	-0.0	-0.0	-1.1	0.37	[illegible]	[illegible]
13	1.00	12.00	-0.0	-0.1	-1.5	[illegible]	-0.11	[illegible]
14	1.00	13.00	-0.0	-0.0	-1.9	0.3[illegible]	-0.12	[illegible]
15	1.00	14.00	-0.0	0.0	-2.3	0.1[illegible]	[illegible]	[illegible]
16	1.00	15.00	-0.0	0.1	-2.8	-0.15	-0.12	[illegible]
17	1.00	16.00	-0.0	0.1	-3.4	-0.4[illegible]	[illegible]	[illegible]
18	1.00	17.00	-0.1	0.2	-4.[illegible]	-0.56	[illegible]	[illegible]
19	1.00	18.00	-0.1	0.2	-4.9	-0.5[illegible]	-0.[illegible]4	[illegible]
20	1.00	19.00	-0.1	0.1	-5.6	-0.4[illegible]	-0.[illegible]4	[illegible]
21	1.00	20.00	-0.1	-0.1	-6.5	[illegible]	[illegible]	[illegible]
22	1.00	21.00	-0.2	-0.2	-7.6	[illegible]	[illegible]	[illegible]
23	1.00	22.00	-0.2	[illegible]	-8.7	[illegible]	[illegible]	[illegible]
24	1.00	23.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
25	1.00	24.00	-0.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
26	1.00	25.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
27	1.00	26.00	[illegible]	[illegible]	[illegible]	0.32	[illegible]	[illegible]
28	1.00	27.00	[illegible]	[illegible]	[illegible]	[illegible]	-0.11	[illegible]
29	1.00	28.00	[illegible]	[illegible]	[illegible]	[illegible]	-0.12	[illegible]
30	1.00	29.00	-1.0	1.0	-20.7	[illegible]	[illegible]	[illegible]
31	1.00	30.00	-1.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
32	1.00	31.00	[illegible]	[illegible]	-25.6	-1.1[illegible]	-0.14	[illegible]
33	1.00	32.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
34	1.00	33.00	-2.[illegible]	[illegible]	-30.5	-0.47	-0.22	[illegible]

STEP	DT	TIME	X	Y	Z	PHI	THETA	PSI
35	1.00	34.00	-2.1	-1.1	-33.7	0.07	-1.28	0.17
36	1.00	35.00	-2.0	-2.6	-36.9	0.01	[illegible]	[illegible]
37	1.00	36.00	-1.9	-4.0	-40.4	1.07	-1.21	[illegible]
38	1.00	37.00	-1.9	-4.9	-44.4	1.46	-1.26	[illegible]
39	1.00	38.00	-2.1	-5.5	-48.2	1.67	[illegible]	[illegible]
40	1.00	39.00	-2.2	-5.3	-51.9	1.61	[illegible]	0.17
41	1.00	40.00	-1.1	-4.0	-55.1	1.42	[illegible]	[illegible]
42	1.00	41.00	-1.0	-3.2	-57.7	0.93	-1.63	[illegible]
43	1.00	42.00	0.9	-0.9	-60.1	0.34	[illegible]	[illegible]
44	1.00	43.00	3.9	2.1	-62.2	-0.14	-1.57	[illegible]
45	1.00	44.00	8.1	4.7	-64.1	-0.41	[illegible]	[illegible]
46	1.00	45.00	12.9	6.2	-65.9	-0.57	[illegible]	[illegible]
47	1.00	46.00	18.0	6.2	-67.2	-1.10	-0.42	[illegible]
48	1.00	47.00	23.2	4.1	-67.9	-1.17	[illegible]	[illegible]
49	1.00	48.00	28.4	1.3	-67.2	-0.60	[illegible]	[illegible]
50	1.00	49.00	33.3	-3.0	-65.3	0.04	-0.57	[illegible]
51	1.00	50.00	38.0	-8.7	-63.6	0.42	-0.62	[illegible]
52	1.00	51.00	42.6	-13.7	-62.3	1.15	[illegible]	[illegible]
53	1.00	52.00	47.1	-18.3	-61.1	1.36	[illegible]	[illegible]
54	1.00	53.00	51.3	-22.5	-59.7	1.33	[illegible]	[illegible]
55	1.00	54.00	55.3	-26.1	-58.2	1.07	[illegible]	[illegible]
56	1.00	55.00	59.2	-29.1	-56.3	0.74	[illegible]	[illegible]
57	1.00	56.00	63.1	-31.9	-55.9	0.12	[illegible]	[illegible]
58	1.00	57.00	66.9	-34.3	-55.3	-0.31	-0.73	[illegible]
59	1.00	58.00	70.2	-36.8	-55.2	-0.71	[illegible]	[illegible]
60	1.00	59.00	73.1	-39.2	-55.9	-1.01	[illegible]	[illegible]
61	1.00	60.00	75.3	-41.6	-56.2	-1.13	-1.77	[illegible]
62	1.00	61.00	76.9	-43.9	-57.1	-1.00	-0.73	[illegible]
63	1.00	62.00	77.7	-47.0	-59.9	-0.80	-0.77	[illegible]
64	1.00	63.00	78.1	-48.0	-60.9	-0.40	[illegible]	[illegible]
65	1.00	64.00	78.2	-50.2	-62.0	-0.12	[illegible]	[illegible]
66	1.00	65.00	78.2	-52.6	-64.5	0.27	[illegible]	[illegible]
67	1.00	66.00	78.4	-54.0	-67.7	0.51	-0.07	[illegible]
68	1.00	67.00	78.9	-57.0	-71.0	0.00	-0.00	[illegible]

```
STEP  DT     TIME        X          Y          Z         PHI       THETA       PSI

 69  1.00   68.00      78.0      -59.0      -75.6       1.24      -0.93      [illegible]
 70  1.00   69.00      78.2      -60.7      -80.2       1.81      [illegible] [illegible]
 71  1.00   70.00      79.4      -62.5      -84.6       2.27      -1.03      -1.74
 72  1.00   71.00      81.2      -64.4      -88.4       2.51      -1.14      [illegible]
 73  1.00   72.00      83.4      -66.9      -92.0       2.51      -1.11      [illegible]
 74  1.00   73.00      86.1      -69.2      -93.3       2.11      -1.05      [illegible]
 75  1.00   74.00      89.3      -71.2      -94.5       1.61      -1.11      [illegible]
 76  1.00   75.00      93.1      -72.7      -93.8       0.95      -1.34      [illegible]
 77  1.00   76.00      97.6      -73.4      -91.2       0.24      -1.40      [illegible]
 78  1.00   77.00     102.0      -74.2      -86.6      -0.51      -1.37      [illegible]
 79  1.00   78.00     106.4      -74.1      -80.9      -1.22      -1.38      [illegible]
 80  1.00   79.00     111.0      -74.1      -74.5      -1.54      -1.42      [illegible]
 81  1.00   80.00     115.5      -74.1      -68.5      -1.84      -1.37      [illegible]
 82  1.00   81.00     119.0      -74.4      -62.5      -2.05      -1.27       0.3?
 83  1.00   82.00     121.7      -74.9      -57.1      -2.13      -1.14      [illegible]
 84  1.00   83.00     124.0      -75.1      -52.4      -2.14      -1.31      [illegible]
 85  1.00   84.00     126.0      -75.3      -48.5      -2.02      -1.29      [illegible]
 86  1.00   85.00     127.8      -75.6      -45.4      -1.85      -1.2?      [illegible]
 87  1.00   86.00     129.4      -75.8      -42.1      -1.59      -1.2?      [illegible]
 88  1.00   87.00     131.0      -76.1      -41.3      -1.27      -1.30      [illegible]
 89  1.00   88.00     132.5      -76.5      -40.4      -0.87      -1.1?      [illegible]
 90  1.00   89.00     134.0      -77.1      -40.1      -0.45      -1.16      [illegible]
 91  1.00   90.00     135.5      -77.6      -40.5       0.02      -1.1?      [illegible]
 92  1.00   91.00     137.0      -78.?      -41.6       0.51      -1.15       1.7?
 93  1.00   92.00     138.4      -78.?      -42.4       1.0?      -1.17      [illegible]
 94  1.00   93.00     139.8      -79.?      -45.7       1.54      -1.21      [illegible]
 95  1.00   94.00     141.?      -80.1      -48.?       2.01      -1.2?      [illegible]
 96  1.00   95.00     142.?      -8?.?      -52.?       2.3?      -1.??      [illegible]
 97  1.00   96.00     144.?      -8?.5      -55.6       2.??      -1.32      [illegible]
 98  1.00   97.00     146.?      -8?.4      -60.6       2.6?      -1.31      [illegible]
 99  1.00   98.00     148.?      -8?.?      -66.?       2.5?      -1.2?      [illegible]
100  1.00   99.00     151.0      -79.5      -70.5       2.42      -1.25      [illegible]
101  1.00  100.00     153.1      -78.?      -72.4       2.17      -1.2?      [illegible]
102  1.00  101.00     155.2      -7?.?      -7?.?       1.8?      -1.27      [illegible]
```

STEP	H	TIME	X	Y	Z	PHI	THETA	PSI
103	[illegible]	[illegible]	157.3	-77.2	[illegible]	1.31	-1.34	[illegible]
104	[illegible]	[illegible]	[illegible]	-75.2	[illegible]	[illegible]	[illegible]	[illegible]
105	[illegible]	[illegible]	162.7	[illegible]	[illegible]	[illegible]	-1.63	[illegible]
106	[illegible]	[illegible]	[illegible]	-67.1	[illegible]	[illegible]	[illegible]	[illegible]
107	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-2.15	[illegible]
108	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-2.37	[illegible]
109	[illegible]	[illegible]	[illegible]	-63.1	[illegible]	[illegible]	[illegible]	[illegible]
110	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
111	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-2.77	[illegible]
112	[illegible]	[illegible]	[illegible]	[illegible]	-121.3	[illegible]	[illegible]	[illegible]
113	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
114	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
115	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
116	[illegible]	[illegible]	[illegible]	[illegible]	-137.3	[illegible]	[illegible]	[illegible]
117	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
118	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
119	[illegible]	[illegible]	[illegible]	[illegible]	-155.3	[illegible]	[illegible]	[illegible]
120	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
121	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
122	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6.71	[illegible]	[illegible]
123	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
124	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
125	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.27	[illegible]	[illegible]
126	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
127	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

STEP	TIME	U BODY	V BODY	W BODY	P BODY	Q BODY	R BODY
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	1.00	0.0	-0.001	-0.004	-0.153	[illegible]	[illegible]
3	2.00	-0.000	-0.001	-0.013	-0.098	[illegible]	[illegible]
4	3.00	-0.000	-0.001	-0.027	-0.120	[illegible]	[illegible]
5	4.00	-0.000	0.002	-0.045	-0.119	[illegible]	[illegible]
6	5.00	-0.000	0.017	-0.066	-0.052	[illegible]	[illegible]
7	6.00	-0.000	0.019	-0.091	0.011	[illegible]	[illegible]
8	7.00	-0.001	0.026	-0.127	0.092	[illegible]	[illegible]
9	8.00	-0.001	0.022	-0.159	0.156	[illegible]	[illegible]
10	9.00	-0.002	0.002	-0.202	0.183	[illegible]	[illegible]
11	10.00	[illegible]	-0.035	-0.247	0.157	[illegible]	[illegible]
12	11.00	-0.015	-0.031	-0.237	0.079	[illegible]	[illegible]
13	12.00	-0.008	-0.119	-0.309	-0.034	-0.004	[illegible]
14	13.00	-0.011	-0.127	-0.386	-0.152	-0.004	0.003
15	14.00	-0.017	-0.092	-0.450	-0.242	-0.004	[illegible]
16	15.00	-0.023	0.011	-0.553	-0.272	-0.005	[illegible]
17	16.00	-0.031	0.159	-0.618	-0.221	[illegible]	[illegible]
18	17.00	-0.040	0.307	-0.643	-0.093	[illegible]	[illegible]
19	18.00	-0.052	0.294	-0.673	0.054	[illegible]	[illegible]
20	19.00	-0.066	0.387	-0.772	0.232	[illegible]	[illegible]
21	20.00	-0.084	0.237	-0.847	0.333	[illegible]	[illegible]
22	21.00	-0.106	-0.460	-1.124	0.385	[illegible]	[illegible]
23	22.00	-0.132	-0.454	-1.176	0.257	[illegible]	[illegible]
24	23.00	-0.162	-0.840	-1.035	0.144	[illegible]	[illegible]
25	24.00	-0.190	-1.001	-1.274	-0.054	[illegible]	[illegible]
26	25.00	-0.222	-1.052	-1.179	-0.273	[illegible]	[illegible]
27	26.00	-0.263	-1.460	-1.564	-0.438	[illegible]	[illegible]
28	27.00	-0.319	-1.619	-1.596	-0.514	-0.015	[illegible]
29	28.00	-0.364	0.912	-2.072	-0.449	[illegible]	[illegible]
30	29.00	-0.420	1.730	-1.702	-0.260	[illegible]	-0.012
31	30.00	-0.555	2.095	-1.250	-0.087	-0.017	[illegible]
32	31.00	-0.596	2.087	-1.178	0.141	-0.020	[illegible]
33	32.00	-0.611	1.342	-1.650	0.362	-0.033	[illegible]
34	33.00	-0.642	1.219	-2.101	0.520	[illegible]	[illegible]

STEP	TIME	U BODY	V BODY	W BODY	P BODY	Q BODY	R BODY
35	34.00	-0.751	-2.056	-3.314	0.577	-0.124	[illegible]
36	35.00	-0.976	-1.777	-2.331	0.521	[illegible]	[illegible]
37	36.00	-1.265	-3.112	-2.417	0.437	[illegible]	[illegible]
38	37.00	-1.450	-3.450	-1.174	0.513	[illegible]	[illegible]
39	38.00	-1.251	-3.548	-0.220	0.121	[illegible]	[illegible]
40	39.00	[illegible]	-3.203	[illegible]	-0.140	[illegible]	[illegible]
41	40.00	-0.301	-2.249	-0.591	-0.425	[illegible]	[illegible]
42	41.00	0.235	-2.323	-2.341	-0.549	[illegible]	-0.172
43	42.00	0.526	-0.797	-4.215	-0.703	0.035	[illegible]
44	43.00	0.932	2.159	-4.652	-0.533	0.179	[illegible]
45	44.00	[illegible]	[illegible]	-3.147	-0.562	0.315	[illegible]
46	45.00	[illegible]	4.060	[illegible]	-0.371	[illegible]	0.182
47	46.00	[illegible]	[illegible]	0.729	-0.127	[illegible]	[illegible]
48	47.00	5.333	2.011	[illegible]	0.315	[illegible]	[illegible]
49	48.00	6.221	[illegible]	-0.842	0.554	[illegible]	[illegible]
50	49.00	[illegible]	1.273	[illegible]	[illegible]	[illegible]	[illegible]
51	50.00	6.311	[illegible]	-2.027	[illegible]	[illegible]	[illegible]
52	51.00	6.125	[illegible]	-2.427	0.307	[illegible]	[illegible]
53	52.00	5.795	-2.141	-1.741	0.052	[illegible]	[illegible]
54	53.00	5.269	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
55	54.00	4.726	-1.357	[illegible]	[illegible]	[illegible]	[illegible]
56	55.00	4.152	-1.476	[illegible]	-0.531	[illegible]	[illegible]
57	56.00	3.560	[illegible]	[illegible]	-0.557	[illegible]	[illegible]
58	57.00	2.994	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
59	58.00	2.427	2.326	[illegible]	[illegible]	[illegible]	[illegible]
60	59.00	1.853	2.034	-1.524	[illegible]	[illegible]	[illegible]
61	60.00	1.431	2.352	[illegible]	[illegible]	[illegible]	[illegible]
62	61.00	1.143	2.402	[illegible]	[illegible]	[illegible]	[illegible]
63	62.00	0.640	2.127	-1.301	[illegible]	[illegible]	[illegible]
64	63.00	0.186	1.552	[illegible]	[illegible]	[illegible]	[illegible]
65	64.00	-0.290	0.465	[illegible]	[illegible]	[illegible]	[illegible]
66	65.00	-0.976	-0.473	[illegible]	[illegible]	-0.225	[illegible]
67	66.00	-1.714	-2.037	[illegible]	[illegible]	[illegible]	[illegible]
68	67.00	-2.413	[illegible]	-2.417	[illegible]	[illegible]	[illegible]

STEP	TIME	U	V	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	−2.749	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	2.242	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	5.712	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	4.557	1.277	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	3.742	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	2.212	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.427	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.237	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.145	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

STEP	TIME	U BODY	V BODY	W BODY	P BODY	Q BODY	R BODY
103	[illegible]	[illegible]	[illegible]	1.007	-0.634	[illegible]	[illegible]
104	[illegible]	[illegible]	-4.322	[illegible]	-0.757	-0.041	[illegible]
105	[illegible]	[illegible]	[illegible]	[illegible]	-0.569	[illegible]	[illegible]
106	[illegible]	[illegible]	[illegible]	-3.061	[illegible]	[illegible]	[illegible]
107	[illegible]	[illegible]	[illegible]	-7.657	[illegible]	[illegible]	[illegible]
108	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
109	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
110	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
111	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
112	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
113	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
114	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
115	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
116	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
117	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
118	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
119	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
120	[illegible]	-4.165	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
121	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
122	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
123	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
124	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
125	[illegible]	[illegible]	[illegible]	[illegible]	17.5[illegible]	[illegible]	[illegible]
126	[illegible]	[illegible]	[illegible]	[illegible]	-251.32[illegible]	[illegible]	[illegible]
127	[illegible]	***************	***************	***************	***************	***************	***************

STEP	TIME	L DOT	V DOT	W DOT	P DOT	Q DOT	R DOT
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	1.00	0.0	-0.001	-0.004	-0.053	-[illegible]	0.001
3	2.00	-0.000	-0.001	-0.010	-0.045	-[illegible]	0.001
4	3.00	-[illegible]	0.000	-0.013	-0.022	-[illegible]	[illegible]
5	4.00	-[illegible]	0.004	-0.019	0.012	-[illegible]	-[illegible]
6	5.00	-[illegible]	0.007	-0.022	0.047	-[illegible]	-0.001
7	6.00	-[illegible]	0.009	-0.025	0.073	-[illegible]	-0.001
8	7.00	-[illegible]	0.005	-[illegible]	[illegible]	-[illegible]	-[illegible]
9	8.00	-0.001	-0.004	-0.037	0.065	-[illegible]	-[illegible]
10	9.00	-0.001	-0.020	-0.042	0.027	-[illegible]	-[illegible]
11	10.00	-[illegible]	-0.037	-0.044	-0.126	-[illegible]	[illegible]
12	11.00	-0.002	-0.044	-0.041	-0.073	-[illegible]	[illegible]
13	12.00	-[illegible]	-0.037	-0.042	-0.113	-[illegible]	[illegible]
14	13.00	-0.004	-[illegible]	-0.057	-0.118	-[illegible]	[illegible]
15	14.00	-[illegible]	[illegible]	-[illegible]	-0.091	-[illegible]	[illegible]
16	15.00	-0.007	[illegible]	-[illegible]	-[illegible]	-0.001	-[illegible]
17	16.00	-[illegible]	[illegible]	-0.063	0.151	-0.001	-[illegible]
18	17.00	-[illegible]	[illegible]	-0.027	0.123	-[illegible]	-[illegible]
19	18.00	-[illegible]	[illegible]	-0.032	0.164	-[illegible]	-[illegible]
20	19.00	-0.014	-[illegible]	-[illegible]	0.166	-[illegible]	-[illegible]
21	20.00	-[illegible]	-0.145	-0.175	0.122	-[illegible]	[illegible]
22	21.00	-[illegible]	-0.326	-[illegible]	[illegible]	-[illegible]	[illegible]
23	22.00	-[illegible]	-[illegible]	-[illegible]	-[illegible]	-[illegible]	[illegible]
24	23.00	-[illegible]	-0.255	[illegible]	-0.155	-[illegible]	[illegible]
25	24.00	-[illegible]	-0.152	[illegible]	-[illegible]	-[illegible]	[illegible]
26	25.00	-[illegible]	[illegible]	-[illegible]	-[illegible]	-[illegible]	-[illegible]
27	26.00	-0.041	[illegible]	-[illegible]	-0.155	-[illegible]	-[illegible]
28	27.00	-0.055	[illegible]	-[illegible]	-[illegible]	[illegible]	-[illegible]
29	28.00	-[illegible]	[illegible]	-[illegible]	[illegible]	[illegible]	-[illegible]
30	29.00	-[illegible]	0.317	[illegible]	[illegible]	[illegible]	[illegible]
31	30.00	-[illegible]	0.365	[illegible]	[illegible]	-[illegible]	[illegible]
32	31.00	-[illegible]	-[illegible]	0.075	[illegible]	-[illegible]	[illegible]
33	32.00	-[illegible]	-0.245	-[illegible]	[illegible]	-[illegible]	[illegible]
34	33.00	-[illegible]	-[illegible]	-[illegible]	[illegible]	-[illegible]	[illegible]

STEP	[illegible]	[illegible] DET	[illegible] DET	[illegible] DET	[illegible] DET	[illegible] DET	[illegible] DET
[illegible]	[illegible]	[illegible]	−1.375	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	−0.335	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	37.00	−0.135	[illegible]	1.243	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	0.171	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	0.225	[illegible]	−0.255	[illegible]	[illegible]
[illegible]	[illegible]	0.507	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	43.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	2.254	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	1.750	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	−0.317	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	0.292	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	1.741	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	65.00	−0.634	−1.343	[illegible]	−0.037	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

STEP	TIME	U DOT	V DOT	W DOT	P DOT	Q DOT	R DOT
69	68.00	-0.426	-0.673	1.607	0.135	-0.011	[illegible]
70	69.00	-0.153	-0.365	1.527	-0.016	-0.041	-0.058
71	70.00	0.312	0.238	1.794	-0.110	[illegible]	-0.042
72	71.00	0.822	0.812	1.205	-0.217	[illegible]	-0.022
73	72.00	1.192	0.626	0.312	-0.264	-0.011	-0.010
74	73.00	1.279	-0.140	-0.544	-0.207	0.011	-0.12
75	74.00	1.225	-0.747	-1.365	-0.127	0.051	[illegible]
76	75.00	1.408	-1.187	-2.174	-0.100	0.122	[illegible]
77	76.00	1.374	1.213	-2.448	-0.003	0.147	[illegible]
78	77.00	1.123	2.507	-1.909	0.032	0.065	0.17
79	78.00	0.975	2.044	1.100	0.111	-0.012	[illegible]
80	79.00	0.516	0.432	1.644	0.163	-0.135	[illegible]
81	80.00	-0.352	-0.547	0.842	0.164	-0.031	[illegible]
82	81.00	-0.692	-0.524	0.131	0.122	0.0	-0.147
83	82.00	-0.952	-1.230	-0.112	0.091	0.012	[illegible]
84	83.00	-0.9	-0.236	-0.174	0.171	0.107	[illegible]
85	84.00	-0.815	-0.211	-0.200	0.053	[illegible]	[illegible]
86	85.00	-0.78	-0.223	-0.2	0.15	0.002	[illegible]
87	86.00	-0.751	-0.258	-0.192	0.145	[illegible]	[illegible]
88	87.00	-0.725	-0.311	-0.163	0.041	0.131	0.12
89	88.00	-0.604	-0.373	-0.109	0.000	0.2	[illegible]
90	89.00	-0.66	-0.457	-0.016	0.021	[illegible]	[illegible]
91	90.00	-0.631	-0.497	0.126	-0.021	[illegible]	[illegible]
92	91.00	-0.591	-0.470	0.323	0.221	[illegible]	[illegible]
93	92.00	-0.547	-0.422	0.56	-0.009	-0.017	[illegible]
94	93.00	-0.405	-0.333	0.727	-0.142	-0.012	[illegible]
95	94.00	-0.422	0.155	0.84	-0.171	-0.01	[illegible]
96	95.00	-0.334	0.295	0.749	-0.089	-0.01	[illegible]
97	96.00	-0.201	0.357	0.57	-0.042	[illegible]	[illegible]
98	97.00	[illegible]	0.247	0.342	[illegible]	[illegible]	[illegible]
99	98.00	-0.245	0.041	0.2	[illegible]	[illegible]	[illegible]
100	99.00	-0.224	-0.211	0.007	-0.102	0.002	[illegible]
101	100.00	-0.20	-0.512	[illegible]	-0.11	[illegible]	[illegible]
102	101.00	-0.114	[illegible]	-0.50	-0.171	[illegible]	-0.01

104/K

STEP	TIME	U DOT	V DOT	W DOT	P DOT	Q DOT	R DOT
[illegible]	[illegible]	0.270	-1.189	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	0.454	[illegible]	[illegible]	-0.122	0.015	[illegible]
[illegible]	[illegible]	0.035	1.571	-4.259	[illegible]	0.045	[illegible]
[illegible]	[illegible]	0.057	3.167	-1.072	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	0.279	[illegible]	0.012	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	-0.234	[illegible]	0.112	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	-0.227	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.003	[illegible]
[illegible]	[illegible]	[illegible]	0.156	0.41?	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	0.511	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	0.615	-0.016	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	0.612	0.023	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	0.12?	[illegible]	0.057	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
117	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.064	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
120	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.143	[illegible]	[illegible]
122	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	4.162	[illegible]	[illegible]	-0.174	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.452	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

APPENDIX D

A PROGRAM TO COMPUTE ONE DIMENSIONAL ASCENT TRAJECTORIES

In order to compute the one dimensional ascent trajectory developed in Chapter III, the program listed on the following page was written.

This program reads in initial conditions and deballasting parameters, computes the acceleration velocity and distance traveled by the vehicle.

Program Listing

```
C      ONE DIMENSIONAL ASCENT TRAJECTORY GENERATOR
       NAMELIST/INCO/WT,B,DV,V,Z,DR,A,D,DT,N,NN
       READ(5,INCO)
       WRITE(6,INCO)
       J=1
       WRITE(6,599)
       WRITE(6,601)
       J=
       DO 10 I=1,NN
       J=J+1
       IF(I.LE.N) B=B+DW
       DV=(-DR*V*ABS(V)-D)/(A+(WT-B)/32.17405)
       V=V+DV*DT
       Z=Z+0.5*(V+VA)*DT
       VA=V
       IF(J.LT.50) GO TO 10
       WRITE(6,599)
       WRITE(6,601)
       J=0
 10    WRITE(6,600)I,WT,B,DV,V,Z
       WRITE(6,599)
       WRITE(6,INCO)
       WRITE(7,INCO)
 599   FORMAT(1H1//)
 601   FORMAT(2X,'STEP    WEIGHT    + BUOYANCY    V DOT         V          '
      C DEPTH')
 600   FORMAT(2X,I4,2X,F10.2,2X,F10.2,2X,F11.3,2X,F10.3,2X,F10.3)
       RETURN
       END
```

Sample Input and Output

Input Data

```
        $INPUT T = 340000.0, [illegible] = 0.0, DW = 0.0, [illegible] = 0.0, Z = 0.0,
DL = 35.237986, A = 3767.80, L = 205.8, WC = 0.50, N = 88, [illegible] = 300,
J = 1, $END
```

```
STEP     WEIGHT    + BUOYANCY      W DOT          W         Z EARTH
  1    140000.00       35.23      -0.004      -0.002        -0.00
  2    140000.00       70.47      -0.009      -0.007        -0.00
  3    140000.00      105.70      -0.013      -0.012        -0.01
  4    140000.00      140.93      -0.017      -0.022        -0.02
  5    140000.00      176.16      -0.022      -0.033        -0.03
  6    140000.00      211.40      -0.026      -0.046        -0.05
  7    140000.00      246.63      -0.030      -0.061        -0.08
  8    140000.00      281.86      -0.035      -0.078        -0.11
  9    140000.00      317.10      -0.039      -0.098        -0.15
 10    140000.00      352.33      -0.043      -0.119        -0.21
 11    140000.00      387.56      -0.047      -0.143        -0.27
 12    140000.00      422.80      -0.052      -0.169        -0.35
 13    140000.00      458.03      -0.056      -0.197        -0.44
 14    140000.00      493.26      -0.060      -0.227        -0.55
 15    140000.00      528.49      -0.064      -0.258        -0.67
 16    140000.00      563.73      -0.068      -0.292        -0.81
 17    140000.00      598.96      -0.072      -0.328        -0.96
 18    140000.00      634.19      -0.076      -0.366        -1.14
 19    140000.00      669.43      -0.079      -0.406        -1.33
 20    140000.00      704.66      -0.083      -0.447        -1.54
 21    140000.00      739.89      -0.086      -0.490        -1.78
 22    140000.00      775.12      -0.090      -0.535        -2.03
 23    140000.00      810.36      -0.093      -0.582        -2.31
 24    140000.00      845.59      -0.096      -0.629        -2.62
 25    140000.00      880.82      -0.099      -0.679        -2.94
 26    140000.00      916.06      -0.102      -0.730        -3.30
 27    140000.00      951.29      -0.104      -0.782        -3.67
 28    140000.00      986.52      -0.106      -0.835        -4.08
 29    140000.00     1021.75      -0.109      -0.889        -4.51
 30    140000.00     1056.99      -0.111      -0.944        -4.97
 31    140000.00     1092.22      -0.112      -1.001        -5.45
 32    140000.00     1127.45      -0.114      -1.058        -5.97
 33    140000.00     1162.69      -0.115      -1.115        -6.51
 34    140000.00     1197.92      -0.117      -1.174        -7.08
 35    140000.00     1233.15      -0.118      -1.232        -7.68
 36    140000.00     1268.39      -0.118      -1.292        -8.32
 37    140000.00     1303.62      -0.119      -1.351        -8.98
 38    140000.00     1338.85      -0.119      -1.411        -9.67
 39    140000.00     1374.08      -0.119      -1.470       -10.39
 40    140000.00     1409.32      -0.119      -1.530       -11.14
 41    140000.00     1444.55      -0.119      -1.590       -11.92
 42    140000.00     1479.78      -0.119      -1.649       -12.73
 43    140000.00     1515.02      -0.118      -1.708       -13.57
 44    140000.00     1550.25      -0.118      -1.767       -14.43
 45    140000.00     1585.48      -0.117      -1.825       -15.33
 46    140000.00     1620.71      -0.116      -1.883       -16.26
 47    140000.00     1655.95      -0.115      -1.941       -17.22
 48    140000.00     1691.18      -0.114      -1.998       -18.20
 49    140000.00     1726.41      -0.112      [illegible]  -19.21
 50    140000.00     1761.65      -0.111      [illegible]  -20.25
```

```
STEP      WEIGHT      + BUOYANCY     W DOT        W        Z EARTH
  51    140000.00      1796.88      -0.109     -2.164     -21.34
  52    140000.00      1832.11      -0.108     -2.218     -22.42
  53    140000.00      1867.34      -0.106     -2.271     -23.54
  54    140000.00      1902.58      -0.104     -2.323     -24.69
  55    140000.00      1937.81      -0.103     -2.374     -25.86
  56    140000.00      1973.04      -0.101     -2.425     -27.06
  57    140000.00      2008.28      -0.099     -2.474     -28.29
  58    140000.00      2043.51      -0.097     -2.523     -29.54
  59    140000.00      2078.74      -0.095     -2.571     -30.81
  60    140000.00      2113.98      -0.094     -2.617     -32.11
  61    140000.00      2149.21      -0.092     -2.663     -33.43
  62    140000.00      2184.44      -0.090     -2.708     -34.77
  63    140000.00      2219.67      -0.088     -2.752     -36.13
  64    140000.00      2254.91      -0.086     -2.796     -37.52
  65    140000.00      2290.14      -0.085     -2.838     -38.93
  66    140000.00      2325.37      -0.083     -2.879     -40.36
  67    140000.00      2360.61      -0.081     -2.920     -41.81
  68    140000.00      2395.84      -0.080     -2.960     -43.28
  69    140000.00      2431.07      -0.078     -2.999     -44.77
  70    140000.00      2466.30      -0.077     -3.037     -46.28
  71    140000.00      2501.54      -0.075     -3.075     -47.81
  72    140000.00      2536.77      -0.074     -3.112     -49.35
  73    140000.00      2572.00      -0.072     -3.148     -50.92
  74    140000.00      2607.24      -0.071     -3.183     -52.50
  75    140000.00      2642.47      -0.069     -3.218     -54.10
  76    140000.00      2677.70      -0.068     -3.252     -55.72
  77    140000.00      2712.93      -0.067     -3.285     -57.35
  78    140000.00      2748.17      -0.066     -3.318     -59.00
  79    140000.00      2783.40      -0.064     -3.350     -60.57
  80    140000.00      2818.63      -0.063     -3.382     -62.35
  81    140000.00      2853.87      -0.062     -3.413     -64.05
  82    140000.00      2889.10      -0.061     -3.444     -65.76
  83    140000.00      2924.33      -0.060     -3.474     -67.49
  84    140000.00      2959.56      -0.059     -3.503     -69.24
  85    140000.00      2994.80      -0.058     -3.533     -71.00
  86    140000.00      3030.03      -0.058     -3.561     -72.77
  87    140000.00      3065.26      -0.057     -3.590     -74.56
  88    140000.00      3100.50      -0.056     -3.618     -76.36
  89    140000.00      3100.50      -0.051     -3.643     -78.18
  90    140000.00      3100.50      -0.046     -3.666     -80.00
  91    140000.00      3100.50      -0.042     -3.687     -81.84
  92    140000.00      3100.50      -0.038     -3.706     -83.69
  93    140000.00      3100.50      -0.034     -3.723     -85.55
  94    140000.00      3100.50      -0.031     -3.738     -87.41
  95    140000.00      3100.50      -0.028     -3.752     -89.28
  96    140000.00      3100.50      -0.025     -3.765     -91.16
  97    140000.00      3100.50      -0.023     -3.776     -93.05
  98    140000.00      3100.50      -0.021     -3.787     -94.94
  99    140000.00      3100.50      -0.019     -3.796     -96.84
 100    140000.00      3100.50      -0.017     -3.804     -98.74
 101    140000.00      3100.50      -0.015     -3.812    -100.64
```

```
STEP      WEIGHT      + BUOYANCY      W DOT          W          Z EARTH
 102    140000.00      3100.50       -0.014       -3.819      -102.55
 103    140000.00      3100.50       -0.012       -3.825      -104.46
 104    140000.00      3100.50       -0.011       -3.831      -106.37
 105    140000.00      3100.50       -0.010       -3.836      -108.29
 106    140000.00      3100.50       -0.009       -3.840      -110.21
 107    140000.00      3100.50       -0.008       -3.844      -112.13
 108    140000.00      3100.50       -0.007       -3.848      -114.05
 109    140000.00      3100.50       -0.007       -3.851      -115.98
 110    140000.00      3100.50       -0.006       -3.854      -117.90
 111    140000.00      3100.50       -0.005       -3.857      -119.83
 112    140000.00      3100.50       -0.005       -3.859      -121.76
 113    140000.00      3100.50       -0.004       -3.862      -123.69
 114    140000.00      3100.50       -0.004       -3.864      -125.62
 115    140000.00      3100.50       -0.004       -3.865      -127.55
 116    140000.00      3100.50       -0.003       -3.867      -129.49
 117    140000.00      3100.50       -0.003       -3.868      -131.42
 118    140000.00      3100.50       -0.003       -3.870      -133.35
 119    140000.00      3100.50       -0.002       -3.871      -135.29
 120    140000.00      3100.50       -0.002       -3.872      -137.23
 121    140000.00      3100.50       -0.002       -3.873      -139.16
 122    140000.00      3100.50       -0.002       -3.874      -141.10
 123    140000.00      3100.50       -0.002       -3.874      -143.04
 124    140000.00      3100.50       -0.001       -3.875      -144.97
 125    140000.00      3100.50       -0.001       -3.876      -146.91
 126    140000.00      3100.50       -0.001       -3.876      -148.85
 127    140000.00      3100.50       -0.001       -3.877      -150.79
 128    140000.00      3100.50       -0.001       -3.877      -152.73
 129    140000.00      3100.50       -0.001       -3.878      -154.66
 130    140000.00      3100.50       -0.001       -3.878      -156.60
 131    140000.00      3100.50       -0.001       -3.878      -158.54
 132    140000.00      3100.50       -0.001       -3.879      -160.48
 133    140000.00      3100.50       -0.001       -3.879      -162.42
 134    140000.00      3100.50       -0.000       -3.879      -164.36
 135    140000.00      3100.50       -0.000       -3.879      -166.30
 136    140000.00      3100.50       -0.000       -3.880      -168.24
 137    140000.00      3100.50       -0.000       -3.880      -170.18
 138    140000.00      3100.50       -0.000       -3.880      -172.12
 139    140000.00      3100.50       -0.000       -3.880      -174.06
 140    140000.00      3100.50       -0.000       -3.880      -176.00
 141    140000.00      3100.50       -0.000       -3.880      -177.94
 142    140000.00      3100.50       -0.000       -3.880      -179.88
 143    140000.00      3100.50       -0.000       -3.881      -181.82
 144    140000.00      3100.50       -0.000       -3.881      -183.76
 145    140000.00      3100.50       -0.000       -3.881      -185.70
 146    140000.00      3100.50       -0.000       -3.881      -187.64
 147    140000.00      3100.50       -0.000       -3.881      -189.58
 148    140000.00      3100.50       -0.000       -3.881      -191.52
 149    140000.00      3100.50       -0.000       -3.881      -193.46
 150    140000.00      3100.50       -0.000       -3.881      -195.40
 151    140000.00      3100.50       -0.000       -3.881      -197.34
 152    140000.00      3100.50       -0.000       -3.881      -199.28
```

```
STEP     WEIGHT      + BUOYANCY      W DOT          W         Z EARTH
 153   140000.00      3100.50       -0.000       -3.881       -201.22
 154   140000.00      3100.50       -0.000       -3.881       -203.17
 155   140000.00      3100.50       -0.000       -3.881       -205.11
 156   140000.00      3100.50       -0.000       -3.881       -207.05
 157   140000.00      3100.50       -0.000       -3.881       -208.99
 158   140000.00      3100.50       -0.000       -3.881       -210.93
 159   140000.00      3100.50       -0.000       -3.881       -212.87
 160   140000.00      3100.50       -0.000       -3.881       -214.81
 161   140000.00      3100.50       -0.000       -3.881       -216.75
 162   140000.00      3100.50       -0.000       -3.881       -218.69
 163   140000.00      3100.50       -0.000       -3.881       -220.63
 164   140000.00      3100.50       -0.000       -3.881       -222.57
 165   140000.00      3100.50       -0.000       -3.881       -224.51
 166   140000.00      3100.50       -0.000       -3.881       -226.45
 167   140000.00      3100.50       -0.000       -3.881       -228.39
 168   140000.00      3100.50       -0.000       -3.881       -230.33
 169   140000.00      3100.50       -0.000       -3.881       -232.28
 170   140000.00      3100.50       -0.000       -3.881       -234.22
 171   140000.00      3100.50       -0.000       -3.881       -236.16
 172   140000.00      3100.50       -0.000       -3.881       -238.10
 173   140000.00      3100.50       -0.000       -3.881       -240.04
 174   140000.00      3100.50       -0.000       -3.881       -241.98
 175   140000.00      3100.50       -0.000       -3.881       -243.92
 176   140000.00      3100.50       -0.000       -3.881       -245.86
 177   140000.00      3100.50       -0.000       -3.881       -247.80
 178   140000.00      3100.50       -0.000       -3.881       -249.74
 179   140000.00      3100.50       -0.000       -3.881       -251.68
 180   140000.00      3100.50       -0.000       -3.881       -253.62
 181   140000.00      3100.50       -0.000       -3.881       -255.56
 182   140000.00      3100.50       -0.000       -3.881       -257.50
 183   140000.00      3100.50       -0.000       -3.881       -259.44
 184   140000.00      3100.50       -0.000       -3.881       -261.39
 185   140000.00      3100.50       -0.000       -3.881       -263.33
 186   140000.00      3100.50       -0.000       -3.881       -265.27
 187   140000.00      3100.50       -0.000       -3.881       -267.21
 188   140000.00      3100.50       -0.000       -3.881       -269.15
 189   140000.00      3100.50       -0.000       -3.881       -271.09
 190   140000.00      3100.50       -0.000       -3.881       -273.03
 191   140000.00      3100.50       -0.000       -3.881       -274.97
 192   140000.00      3100.50       -0.000       -3.881       -276.91
 193   140000.00      3100.50       -0.000       -3.881       -278.85
 194   140000.00      3100.50       -0.000       -3.881       -280.79
 195   140000.00      3100.50       -0.000       -3.881       -282.73
 196   140000.00      3100.50       -0.000       -3.881       -284.67
 197   140000.00      3100.50       -0.000       -3.881       -286.61
 198   140000.00      3100.50       -0.000       -3.881       -288.55
 199   140000.00      3100.50       -0.000       -3.881       -290.50
 200   140000.00      3100.50       -0.000       -3.881       -292.44
 201   140000.00      3100.50       -0.000       -3.881       -294.38
 202   140000.00      3100.50       -0.000       -3.881       -296.32
 203   140000.00      3100.50       -0.000       -3.881       -298.26
```

thesT88
Emergency ascent trajectories for deep s
3 2768 001 88874 6
DUDLEY KNOX LIBRARY